EPA

Office of Research and Development

Best Practices for Controlling Lead and Copper Release

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LCR Widespread Misconceptions

- Health effects in TT rules less serious than in MCL regulations
  - LCR, GWR, SWTR, etc. all reflect serious public health dangers
  - MCL not set because of issues surrounding “feasibility”
  - **MCLG = 0, well-documented absence of threshold for detriment in DW**
  - Risk estimations based on IQ detriments/BLL elevations point to MCL < PQL (0.005 mg/L)
  - It has unfortunately become almost a “sport” in the US to skew sampling and site selection to intentionally avoid uncovering elevated lead levels.
- WQPs were meant to predict/control lead levels by themselves
  - Keep treatment from being turned off
  - Keep inhibitor dosages & pH control from being cut to save $$$
  - Keep required repairs to treatment on tight schedule
  - Prevent willy-nilly variations in water sources

New Research View of Optimal Corrosion Control Treatment

- OCCT includes ***both pure corrosion and control of metal release*** (what causes unhealthy exposures)
- OCCT is *much more* than simply adjusting pH or adding phosphate.
- Both soluble and some particulate Pb release can be controlled by treatment
- Metal solubility is important factor
  - Varies by factor of 5 to 10 or more across systems
  - Can minimize consumer's chronic/background exposure to metals because soluble release is readily preventable
  - The nature of pipe scales reflecting past treatment history dictates the direction and level of success of lead control approaches
- Episodic Pb spikes cannot be *totally* prevented when lead sources remain present.

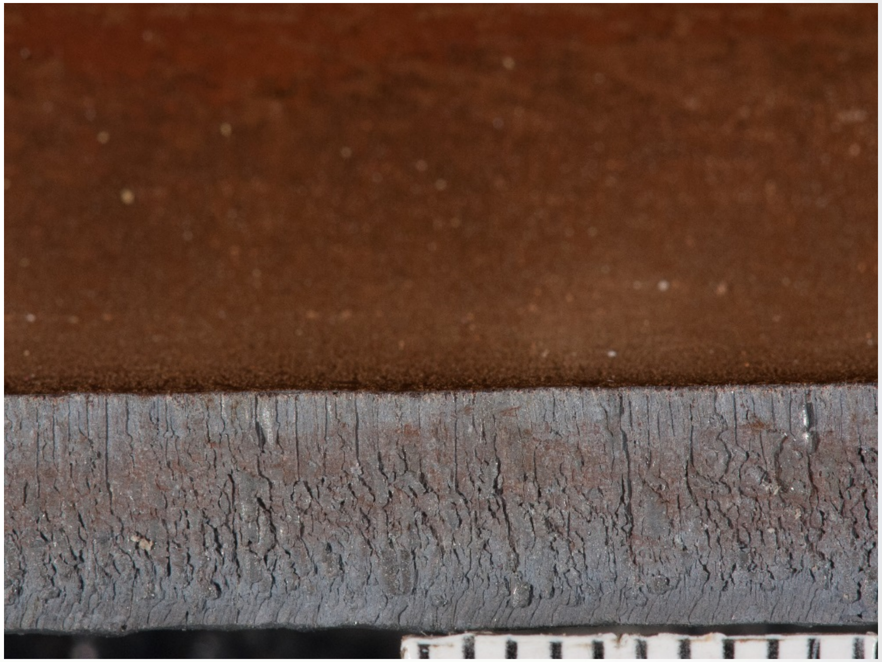
“Corrosion Control” Treatment is Intertwined with All Treatments Affecting DS Water Chemistry

To achieve OCCT, overall process control and distribution system water quality optimization must also be achieved. OCCT is not an independent, separate process.

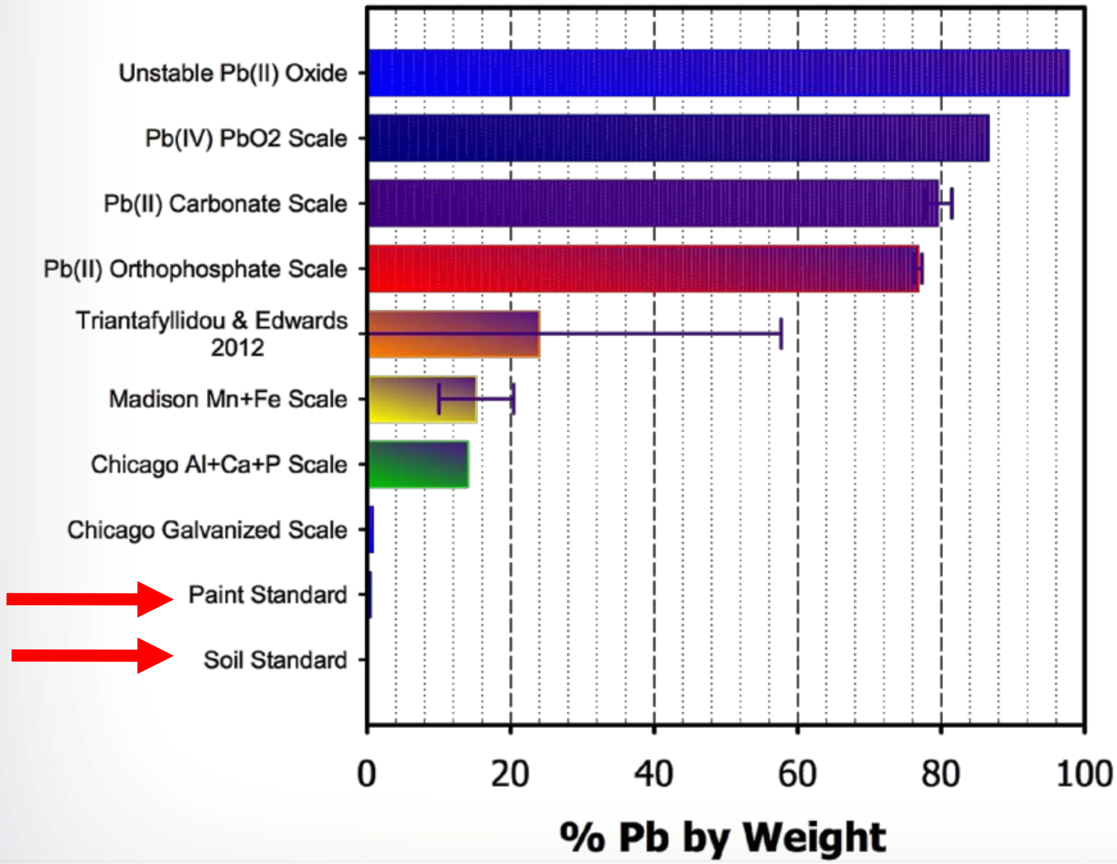
Lead Pipes are Forever…

Lead Pipes Won't Go Away Any Time Soon

Installed Right After the Civil War in Cincinnati: Any Signs of Failure *after 150 Years*?



Drinking through Lead-Painted Pipes



Pipe Scale Particles Have as Much or More Lead Than Pb in Paint or Soil

Erosion and suspension of particles from pipe corrosion scales and deposits is inevitable.

Even minute amounts are greater relative exposure than paint or soils

General Factors Governing Pb Levels

- Sampling protocol
- Intrinsic Pb solubility of surface material (water chemistry)
- Rate of dissolution in short stagnation times
  – Galvanic driving force
  – Diffusion from surface (reaches steady state)
- Length of contact with lead source
- Nature of lead release
  – Particulate
  – Soluble

Additional points:
- There are no accurate substitutes or surrogates for directly monitoring lead release.
- Corrosion "indices", surrogate pipe rigs, and water quality parameters do not adequately predict **lead** levels at the **taps**.

The Ultimate Solution: Full LSL Removal

- The *correct interpretation* of the ORD Madison, WI study:
  - once the perpetual lead source was removed (the LSL), there was a lag time *resulting from the reservoir of lead in the iron- and manganese-rich deposition that accumulated in the premise plumbing* from some wells.
  - The premise lead release reduced dramatically following full LSL replacement, *but it took around 4 years to reach minimum*.
  - The protective PbO_2 scale layer formation was inhibited by Mn
- Published and presented studies by others in Guelph (ON) and Halifax (NS) *without the surface fouling deposits*, showed *nearly immediate* total reductions in lead release from the premise plumbing.
- Make your treatment life easier and cheaper by getting them out

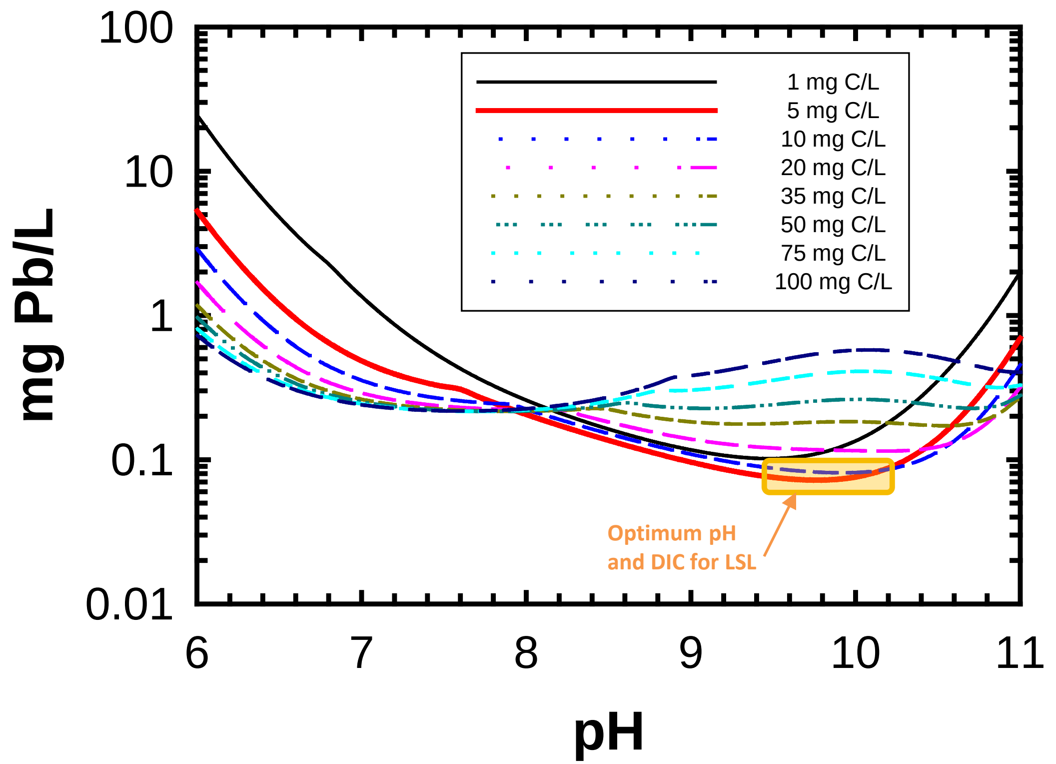
There Are Many Types of Scale on Pb Pipe

- Simple carbonate or hydroxycarbonate Pb(II) mineral
- Simple Pb(II) orthophosphate mineral
- Simple PbO_2 solid phase, by itself or mixed with Pb(II) phases
- Mix of Pb(II) phases
- Protective “diffusion barrier” materials
  - Could be insoluble amorphous Pb(II) phase
  - Adherent non-Pb phase
- Surface fouling deposit
  - Primarily not made of lead, usually not crystalline
  - Lead may sorb to surface
  - Often not adherent

Simple "Carbonate Passivation"

Low DIC/High pH Strategy More Difficult with LSLs than Leaded Solder or Brass

- The first formed solids with major treatment change.
- It is only possible to nearly minimize Pb levels at pH >> 9. Can only work in "soft" waters.
- Likely never as good as PbO_2 or orthophosphate
- Formation of Pb(II) carbonate or hydroxycarbonate much faster than formation rate of Pb(II) orthophosphate films
- Formation of Pb(II) hydroxycarbonate solid is a precursor to the formation of less-soluble protective films of either Pb(II) orthophosphates or PbO_2

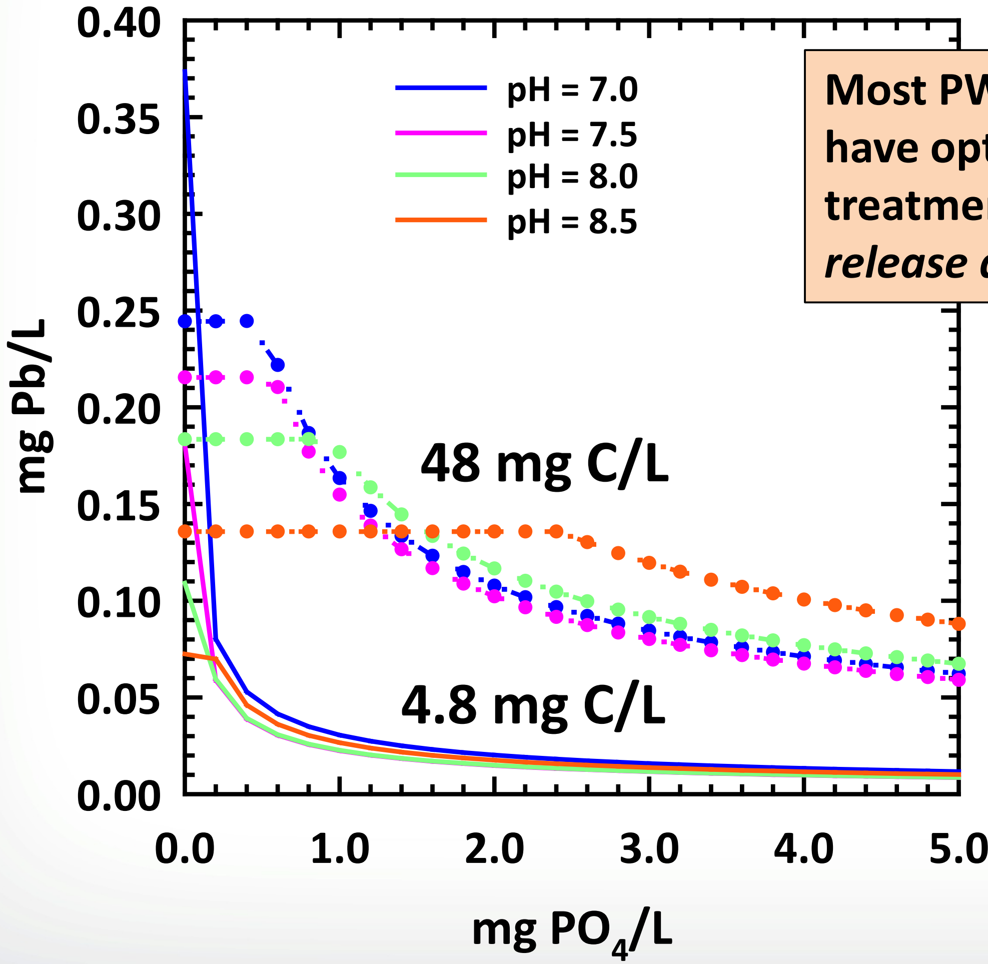


[Seemingly] New Ideas on pH/DIC Relation to Orthophosphate Dosing

"Point of Diminishing Returns" is key to cost-effective lead release control and exposure reduction, if secondary interferences are removed

Point of Diminishing Returns for Ortho-P

Effectiveness Depends on Dose, DIC, pH and "Cleanliness" of Pipe Surface



Most PWSs with LSLs currently do not have optimized corrosion control treatment *in terms of minimizing Pb release and exposure*.

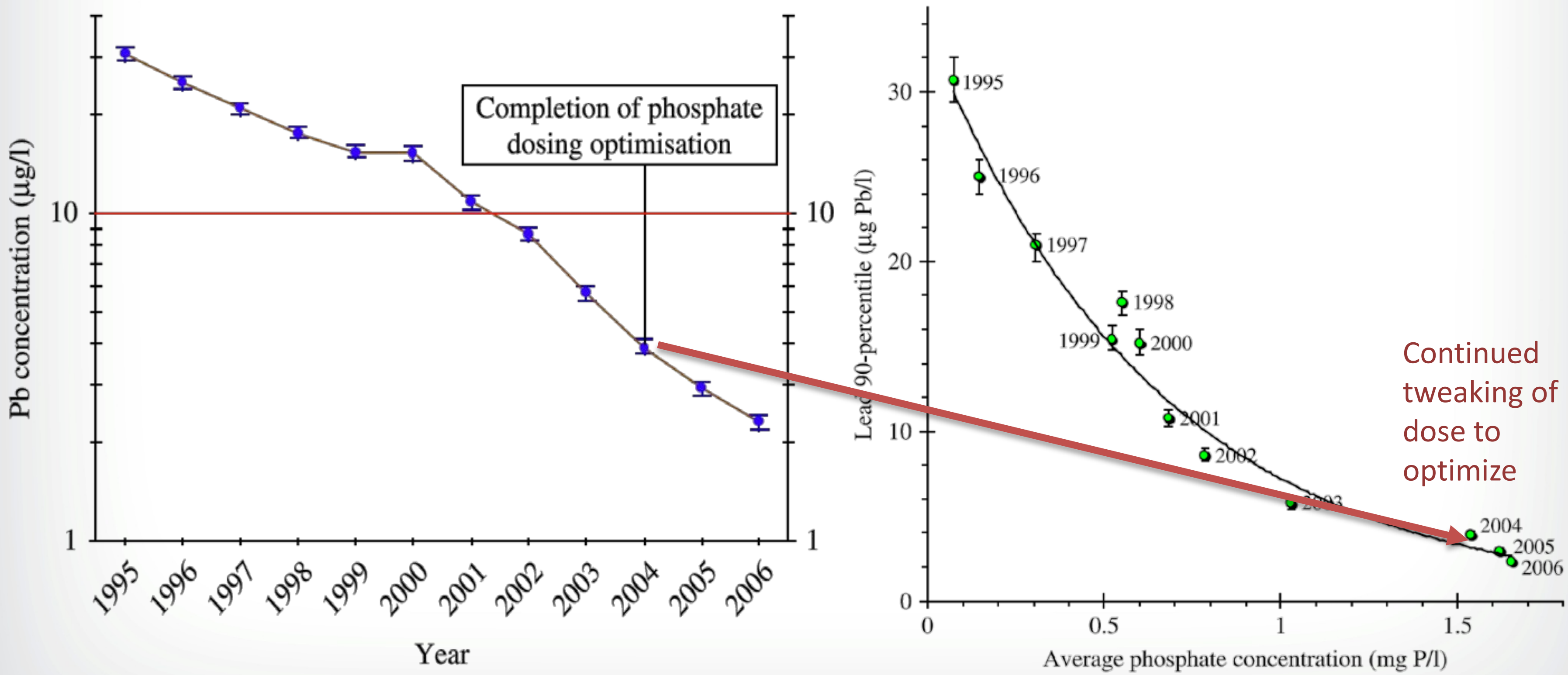
- pH less critical at low TIC
- pH less critical at high PO_4
- Point of diminishing returns higher with high TIC
- Faster Pb reduction at high PO_4

Typical UK Dosages: 4-6 mg/L

![EPA logo]

Treatment Works on Both Soluble & Particulate Release

Aggregated UK Monitoring Data: Used two-pronged approach:
(1) Initial dose estimation by pipe rig study for background water
(2) RDT tap monitoring to assess progress & exposure

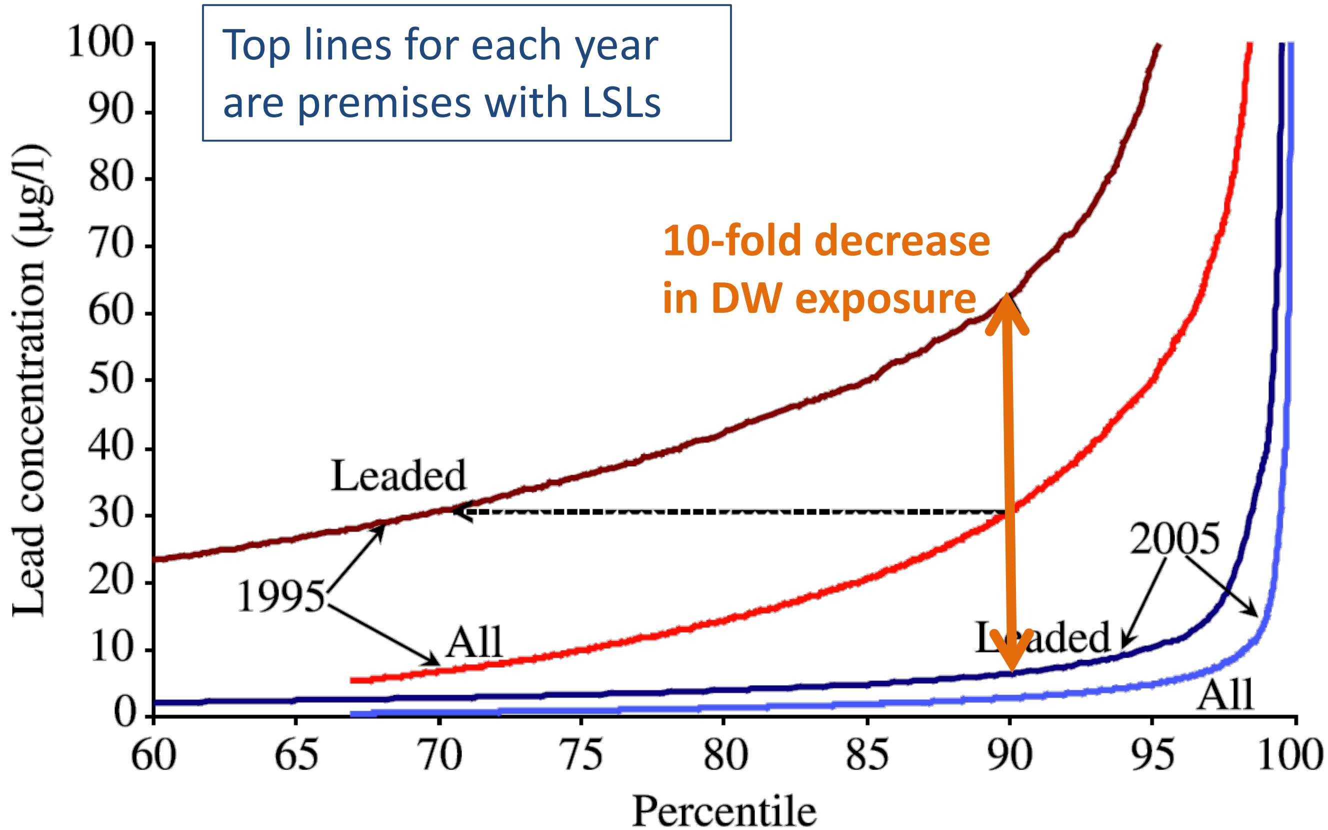


Continued tweaking of dose to optimize

mg/L as PO_4 = 3 x mg/L as P

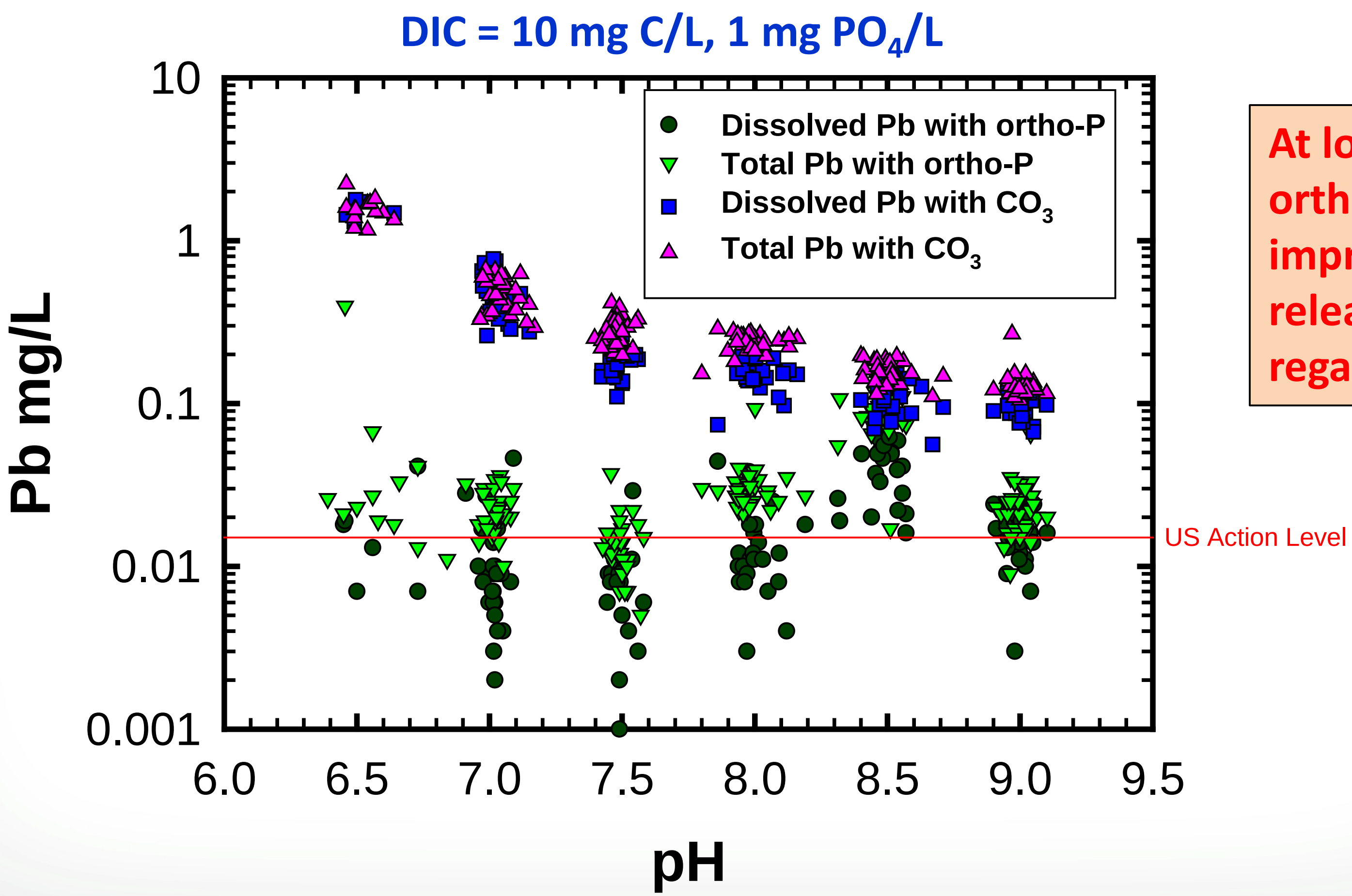
Cardew, P. T. Measuring the benefit of orthophosphate treatment on lead in drinking water. *J Water Health* **2009,** *7* (1), 123-31.

UK Decade of Pb Optimization Progress for Both LSLs and Other Pb Sources



Cardew, P. T. Measuring the benefit of orthophosphate treatment on lead in drinking water. *J Water Health* **2009,** *7* (1), 123-31.

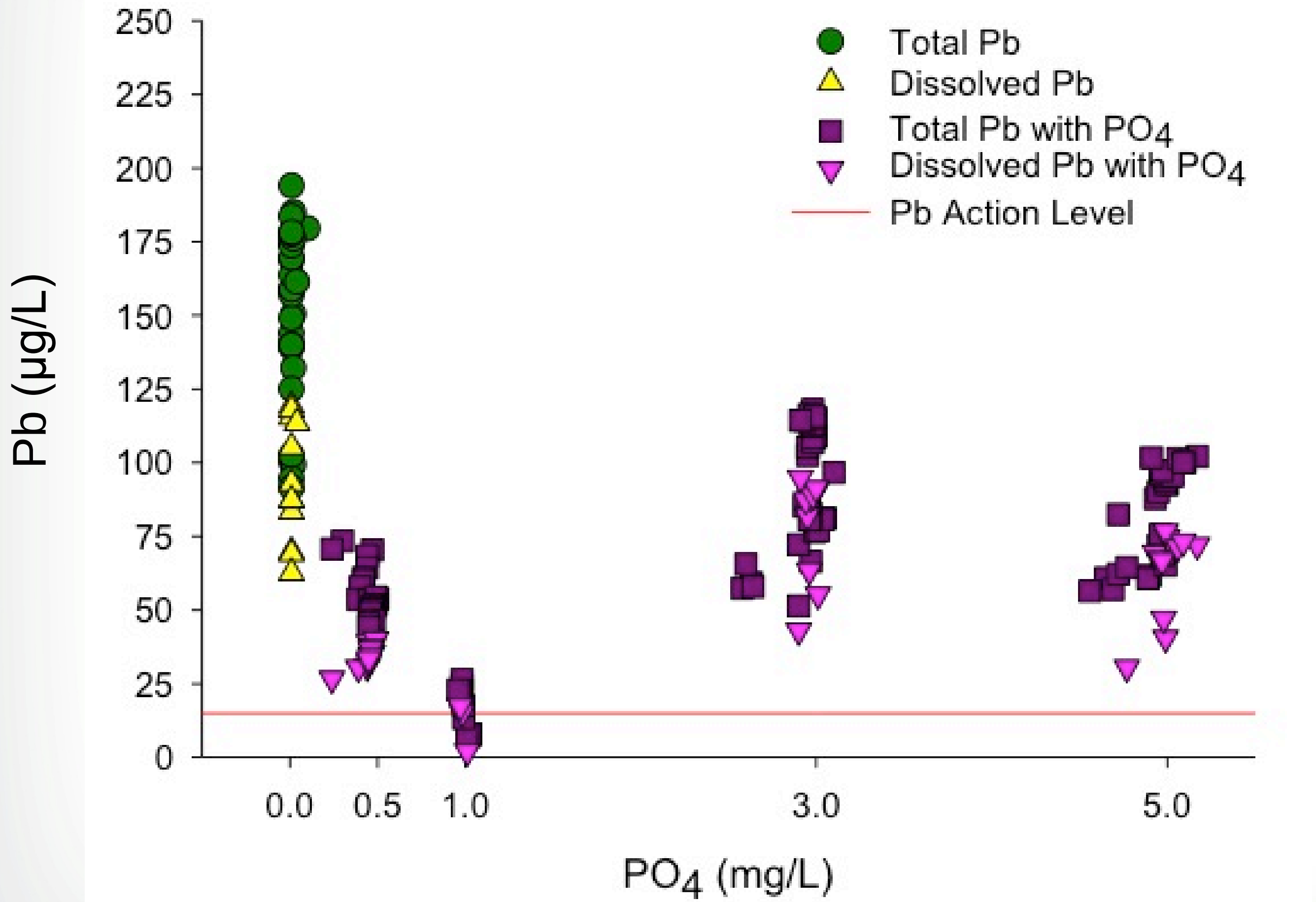
Effect of pH and PO_4 on Pb Release



At low DIC, orthophosphate improves lead release regardless of pH

Schock, M. R.; DeSantis, M. K.; Metz, D. H.; Welch, M. M.; Hyland, R. N.; Nadagouda, M. N. *Revisiting the pH Effect on the Orthophosphate Control of Plumbosolvency, Proc. AWWA Annual Conference and Exposition, Atlanta, GA,* **2008.**

Ortho-P Can Work at pH 9.0 (DIC 6 mg/L)

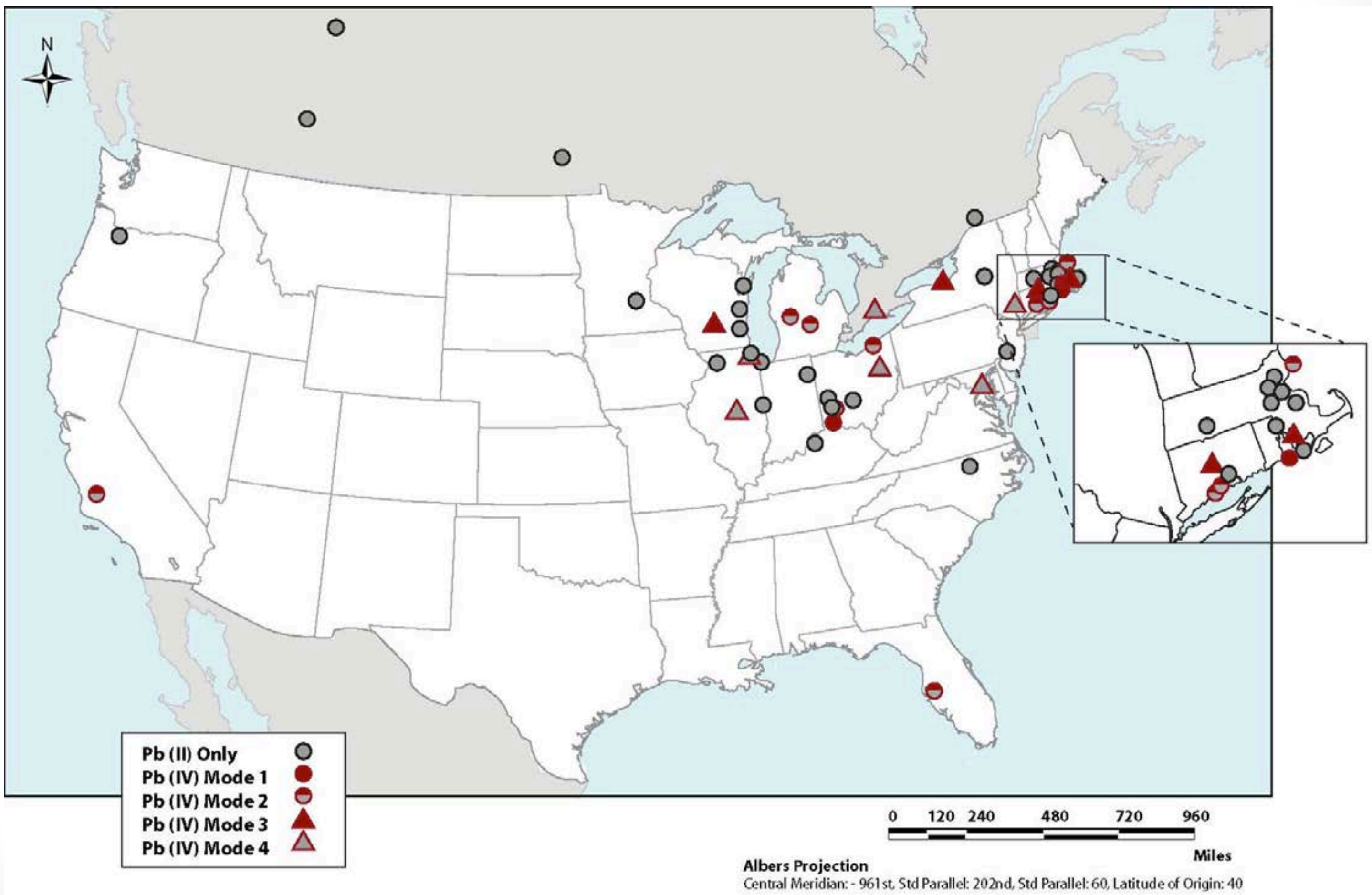


- **Preliminarily, not necessarily same trend as at pH 7-8.**
- **Pb may not decrease more with higher PO_4**
- **Must do dose optimization study for your own water quality, especially at high pH**

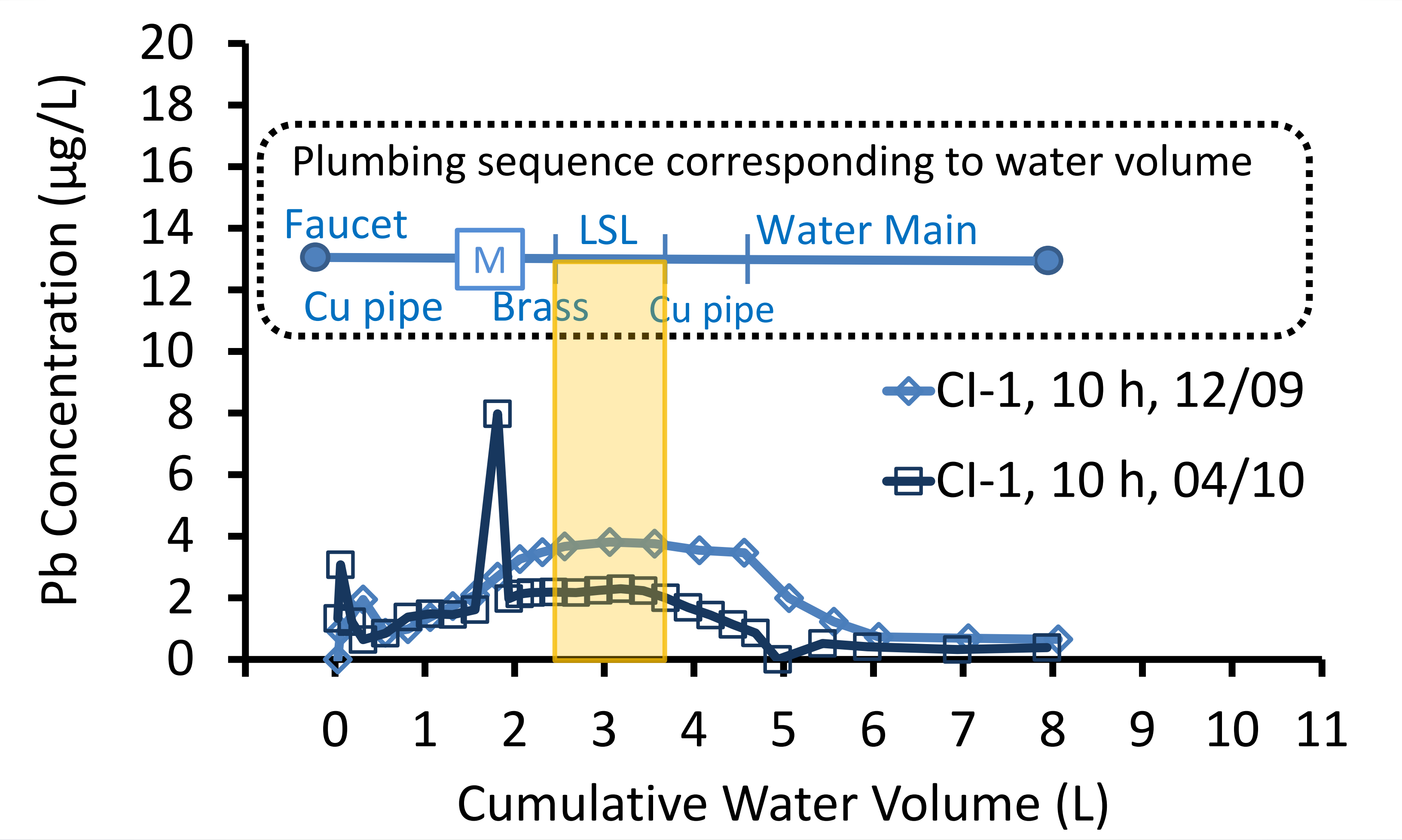
Miller, S. A. Investigation of Lead Solubility and Orthophosphate Addition in High pH Low DIC Water. Master of Science, Department of Biomedical, Chemical, and Environmental Engineering, College of Engineering and Applied Science, University of Cincinnati, Cincinnati, OH, **2014**.

Modes of PbO_2 in LSL Scales

About 1/3 of 52 systems where scale was analyzed had some amount of PbO_2

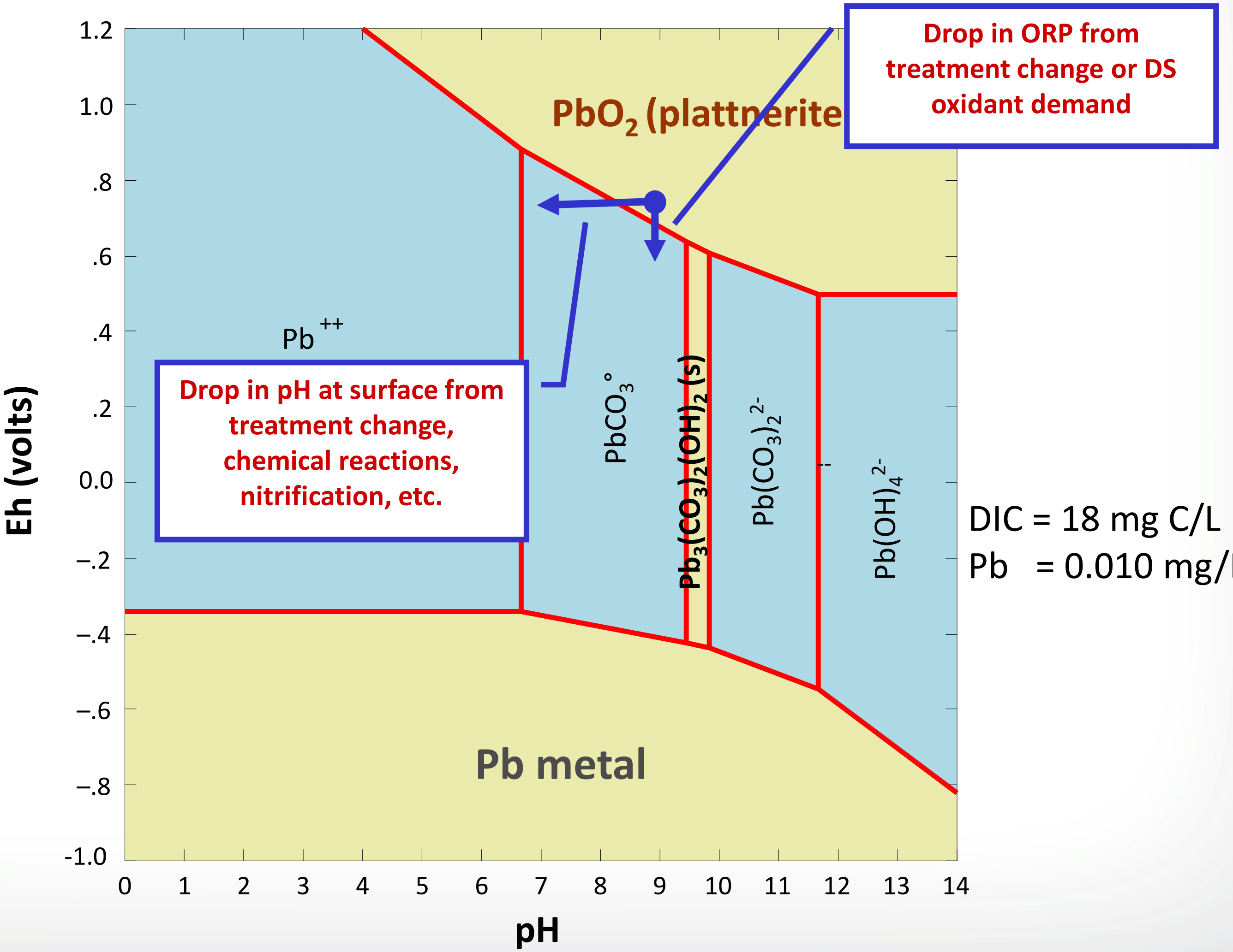


Example Profile of PbO_2 Scale House



Chemical Changes Cause Dissolution of PbO_2

Disinfectant demand in DS must be controlled and enough free chlorine consistently maintained throughout LSL area



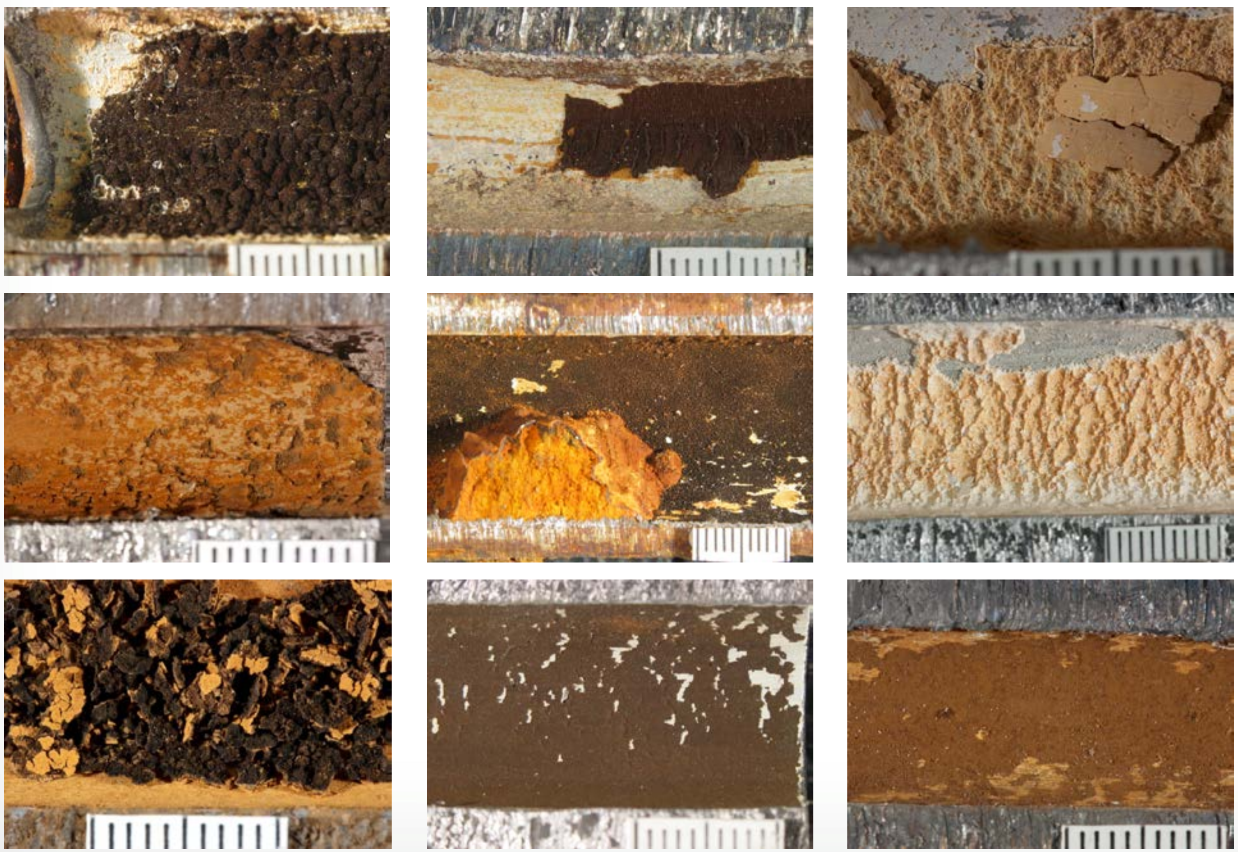
DIC = 18 mg C/L
Pb = 0.010 mg/L

Significant non-Pb Scale Components

May be more prevalent than “normal” lead solids across all systems

Surface Fouling May Be the Norm

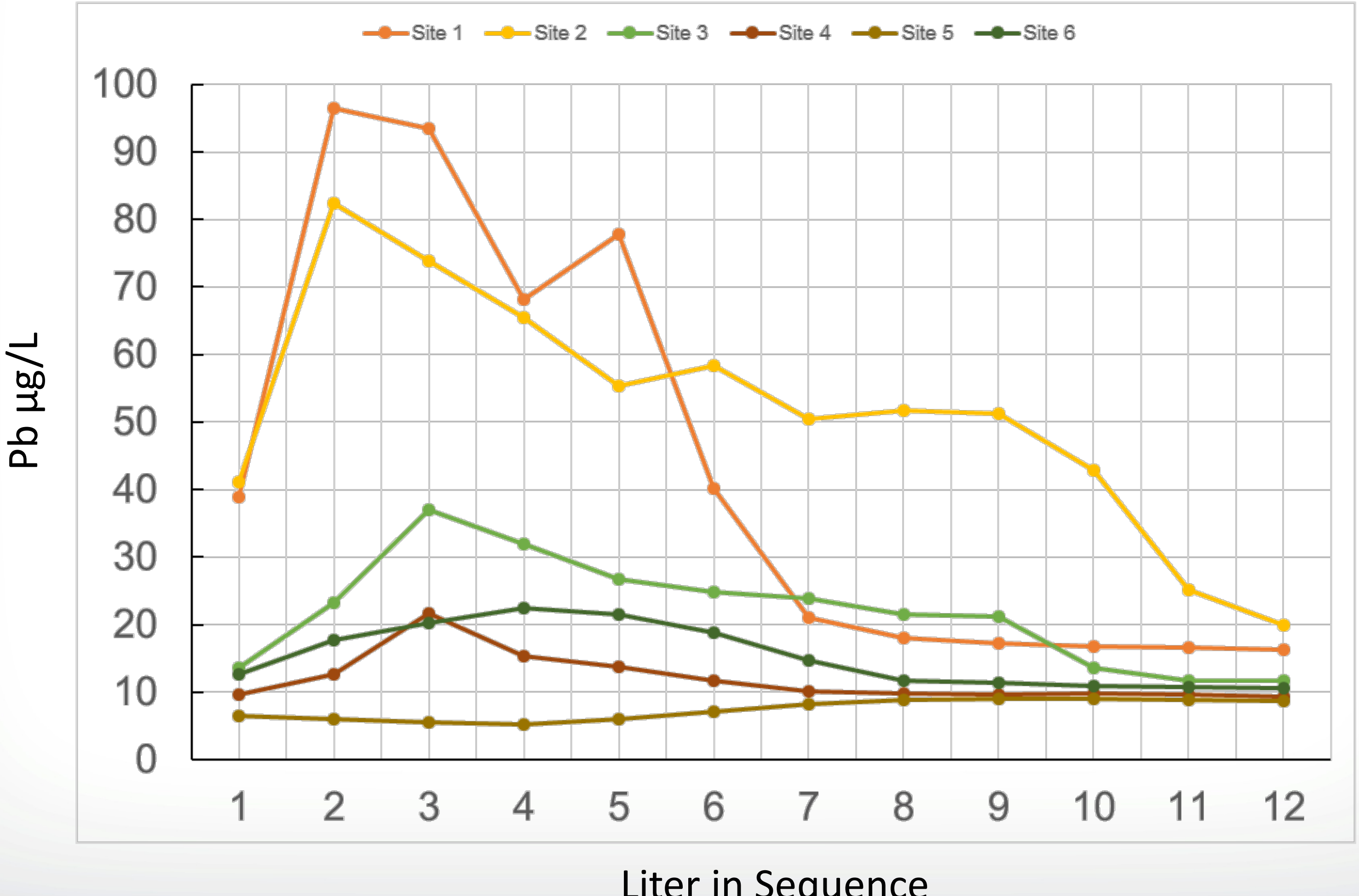
18 of 52 DWDS studied by EPA show external layer deposits almost completely made of poorly crystalline Mn, Fe, Al, Ca, or Si-rich phases



Adding orthophosphate or just adjusting pH with thick coatings likely will not minimize lead release until causes of the interfering buildups are controlled

Pb Profiles in System with Al-Si-Ca Rich Deposit

< 10% Pb in surface scale, no crystalline Pb phases at surface



Blended Phosphates Do Not Fit Orthophosphate Predictions

Not Forming Simple Pb(II) Orthophosphate Solids

Sample ID	Layer	Al	Ca	Fe	P	Pb	Zn
Pb-A & Pb-B Average	1	16	7	1.9	11	14	0
	2	12	4	0.5	6	39	0
	3	4.8	1	0.4	2.1	62	0
	4	0.4	0	0.1	0.2	80	0
G	1	4.2	1	31	2.7	0.8	22
	2	0.5	1	57	0.2	0.1	5.8
	3	0.6	0	56	0.1	0.1	7.8

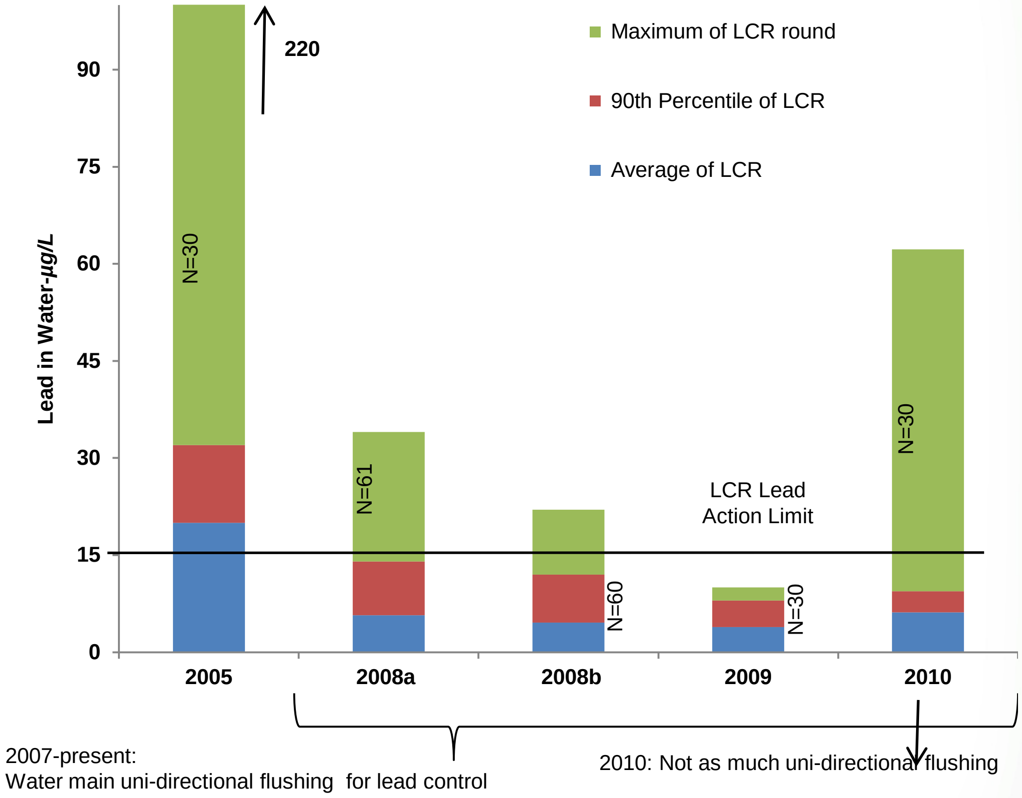
*Elements are expressed in weight %.

Impacts of Dissimilar Coatings

- Sorption/entrainment of Cu or Pb
- Continues exposure after LSLs removed
- Degrades performance of phosphate inhibitors
- Prone to particulate Pb/Cu release
- Must understand treatment change impacts on coatings, as well as Pb andCu
- Cannot predict optimization or effectiveness of phosphate addition from theory, *but can pilot test with exhumed pipes*
- Cannot form pure stable PbO_2 layer
- **To control lead release, you must control Fe corrosion/deposition, finished water Mn, DBP precursors, coagulant carry-over, etc.**

Manganese Deposit Removal Improved Lead Release

To achieve OCCT, overall process control and distribution system water quality optimization must also be achieved. OCCT is not an independent, separate process.



Schock, M. R.; Cantor, A. F.; Triantafyllidou, S.; DeSantis, M. K.; Scheckel, K. G. Importance of Pipe Deposits to Lead and Copper Rule Compliance. *Journal - American Water Works Association* ***2014,*** *106 (7), E336-E349.*

Copper

Identifying Pb and Cu High Release Sites

As early as 1992, *poor to no correlation* between sites with high lead and high copper were being observed in AWWA LCR analysis

Only in *acidic oxic waters* is there good agreement

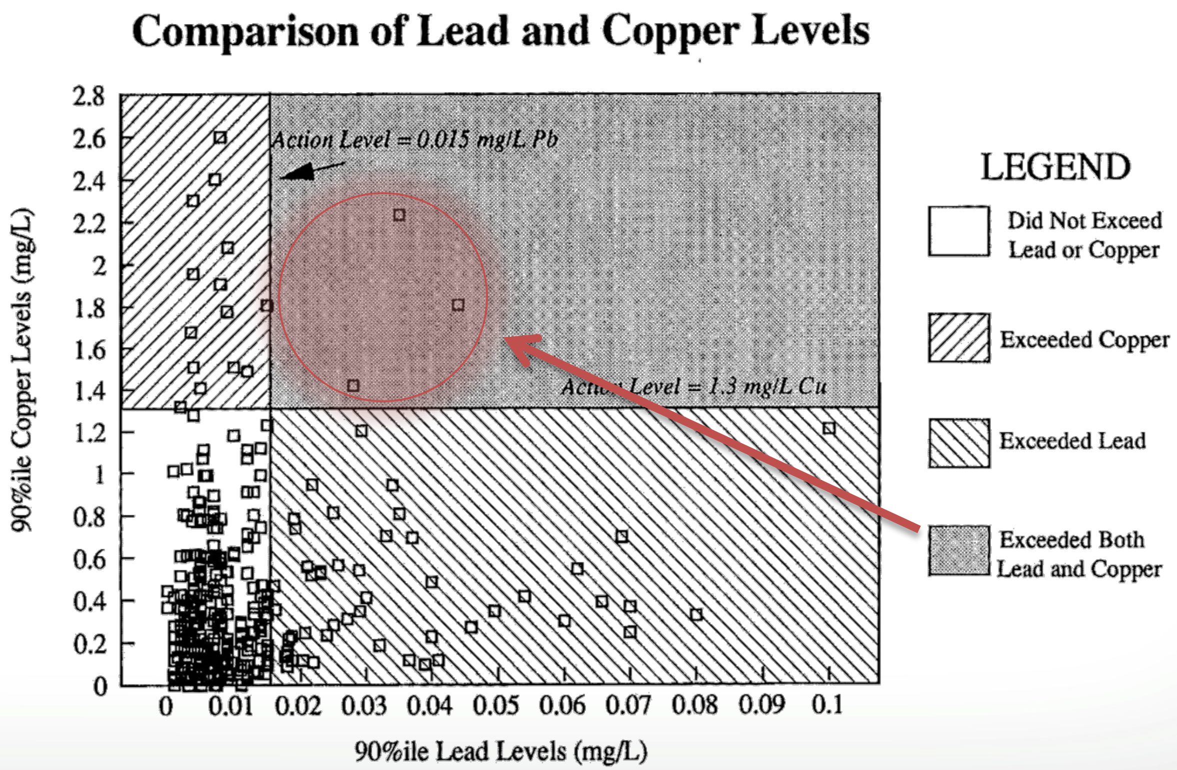


Figure IV-13 1992 JMM-EES-PK Report

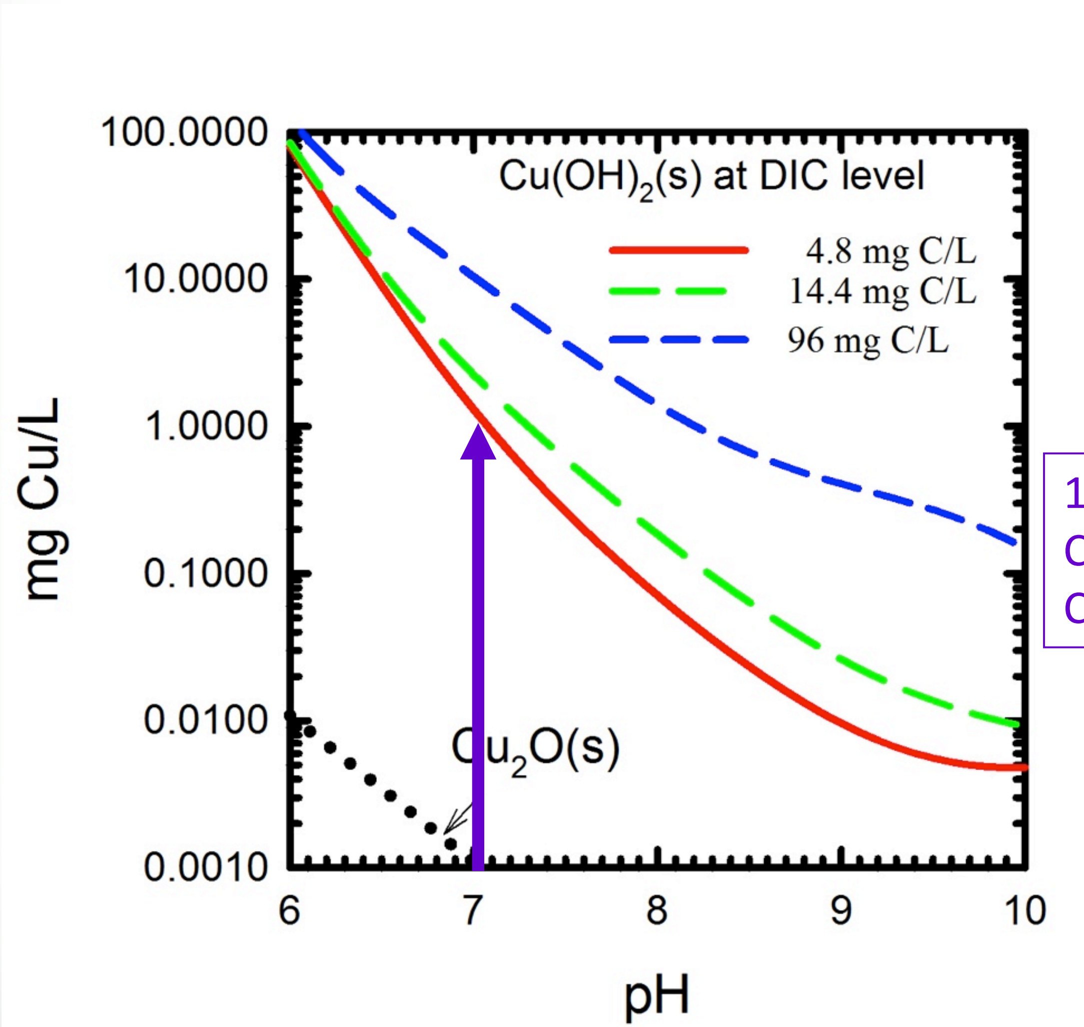
Science Issues with Current LCR Cu Sampling

- Chemistry and mechanisms of Pb and Cu release have major differences
- Newest Tier 1 LCR sites are **25** years old and *get older every monitoring round*, exactly the opposite of copper release risk
- If a site has an LSL, copper *may be sampled from galvanized plumbing*
- States may deem “optimized” even if people have copper levels above the AL, for which there is no public notification
- Systems often have zones with different water quality: water quality where Tier 1 Pb sites exist may be considerably different than where high copper levels exist
- Site targeting does not try to capture aggressive waters.

Major Factors in Cu Release

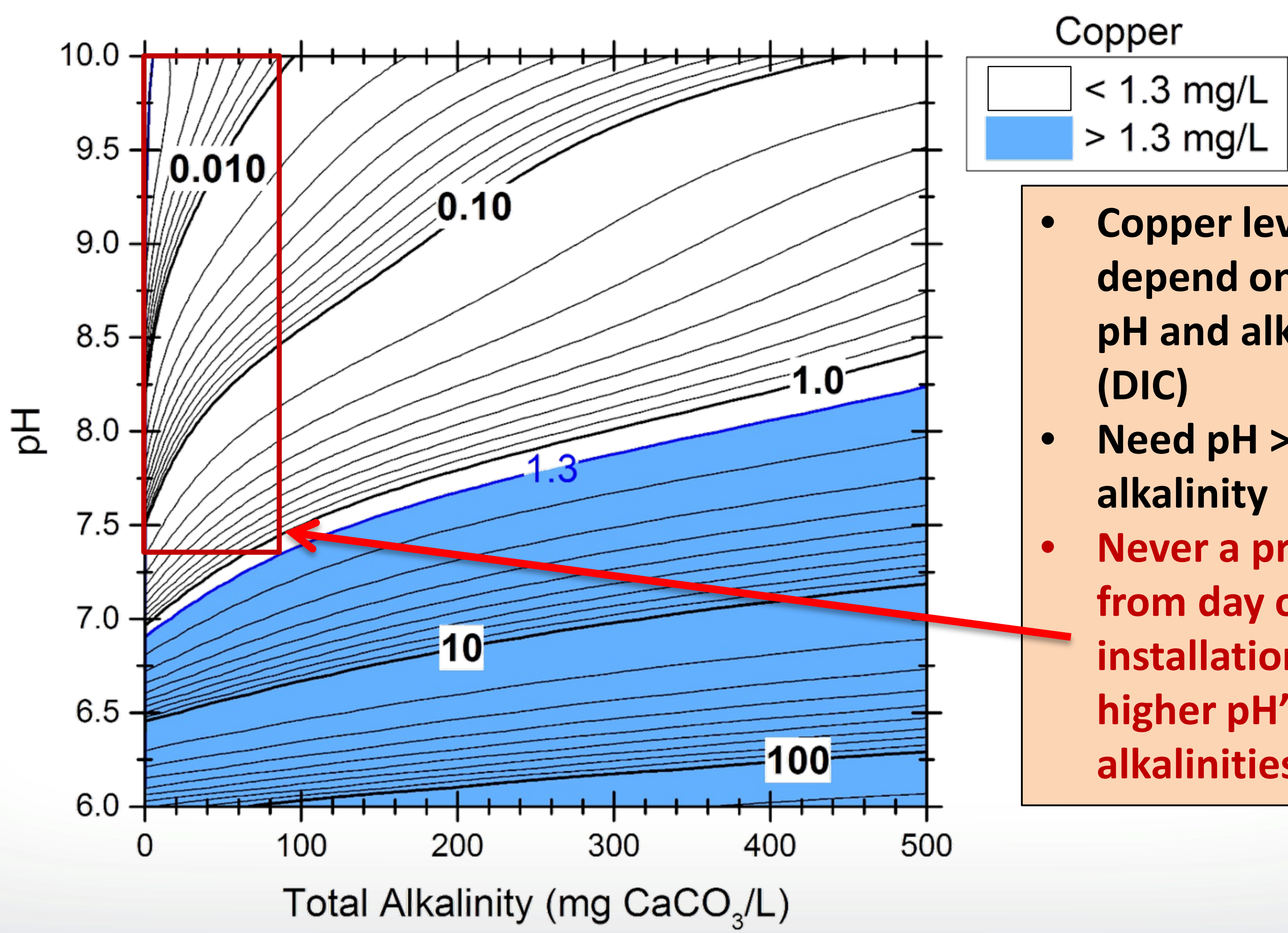
- ORP/persistence of oxidants
- pH/Alkalinity/DIC = solubility
- [*Ortho*]phosphate
- Aging (several variables): Scales recrystallize by themselves, to less soluble forms over years to decades
- Stagnation time (behavior differs from Pb)
- Flow regime/surface area to volume ratio of real pipe installations versus simulation studies such as coupons (affects rate of aging and stagnation release)

No Copper Corrosion in Anoxic Waters



1000x INCREASE in Cu solubility for fresh Cu(II) vs Cu(I) at pH 7

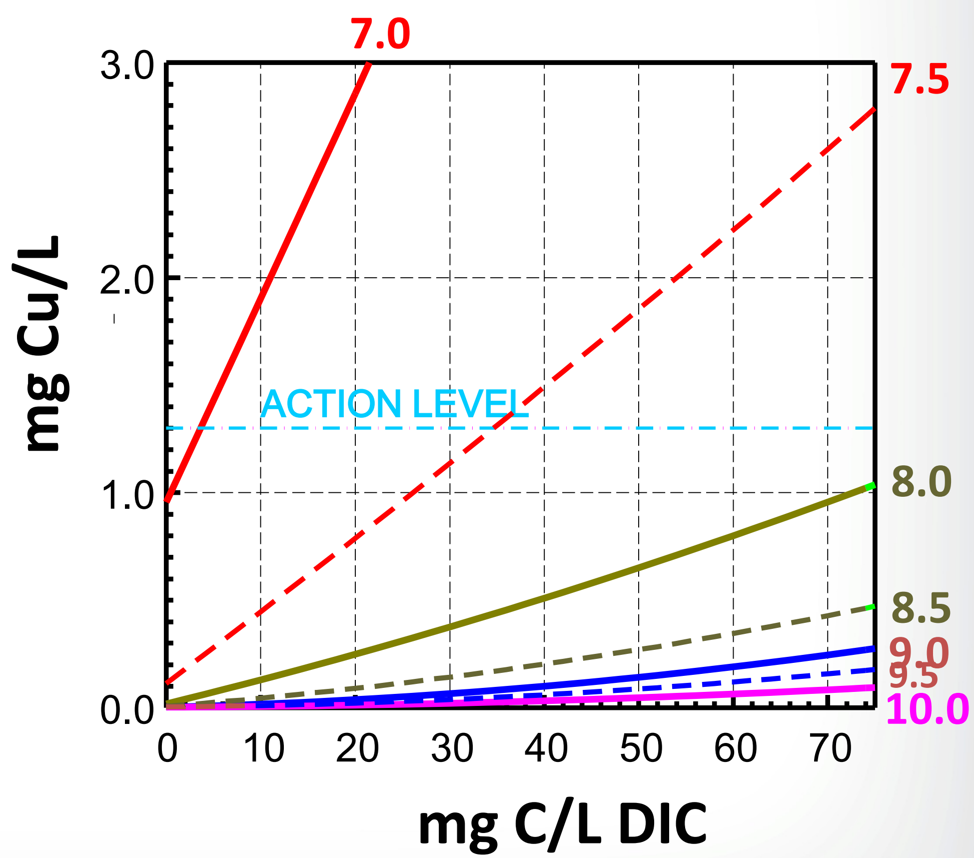
Summary of Cu(II) Vulnerability in New Plumbing (No PO_4)



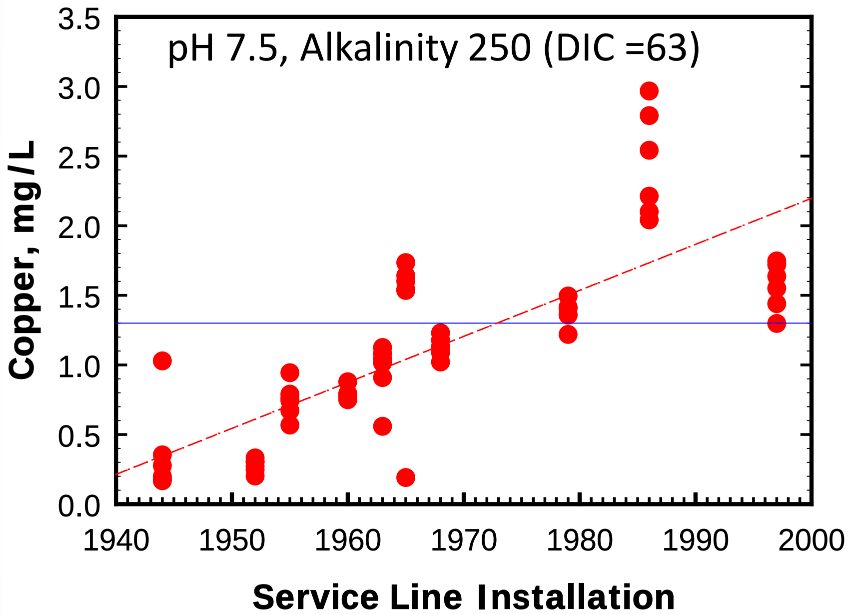
- Copper levels depend on both pH and alkalinity (DIC)
- Need pH > 7, any alkalinity
- Never a problem from day of installation at higher pH's, lower alkalinities

Cu(II) Solubility & pH Adjustment

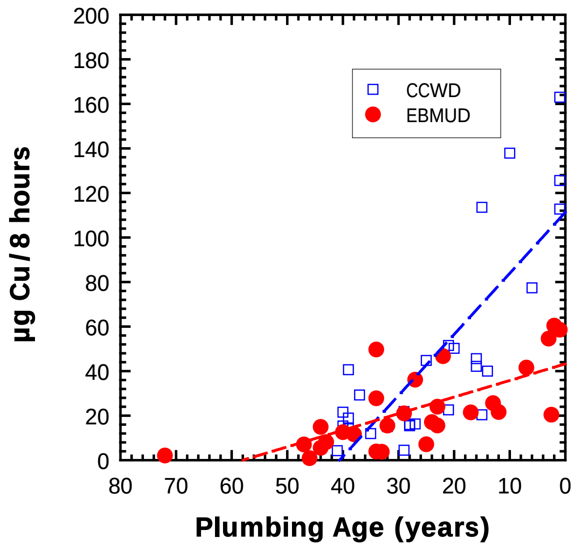
- If **pH > 7.5**, no problems if **DIC < 35**
- If **DIC < 5**, no problems if **pH > 7**
- If DIC > 35-40, scaling & buffering prevents sufficient pH adjustment to solve problems
- To minimize Cu for WWTP discharge optimization, pH > 9 needed



Cu Aging: The Missing Critical Factor



Schock, M. R.; Sandvig, A. M. *Jour. AWWA* ***2009, 101 (7), 71-82.***



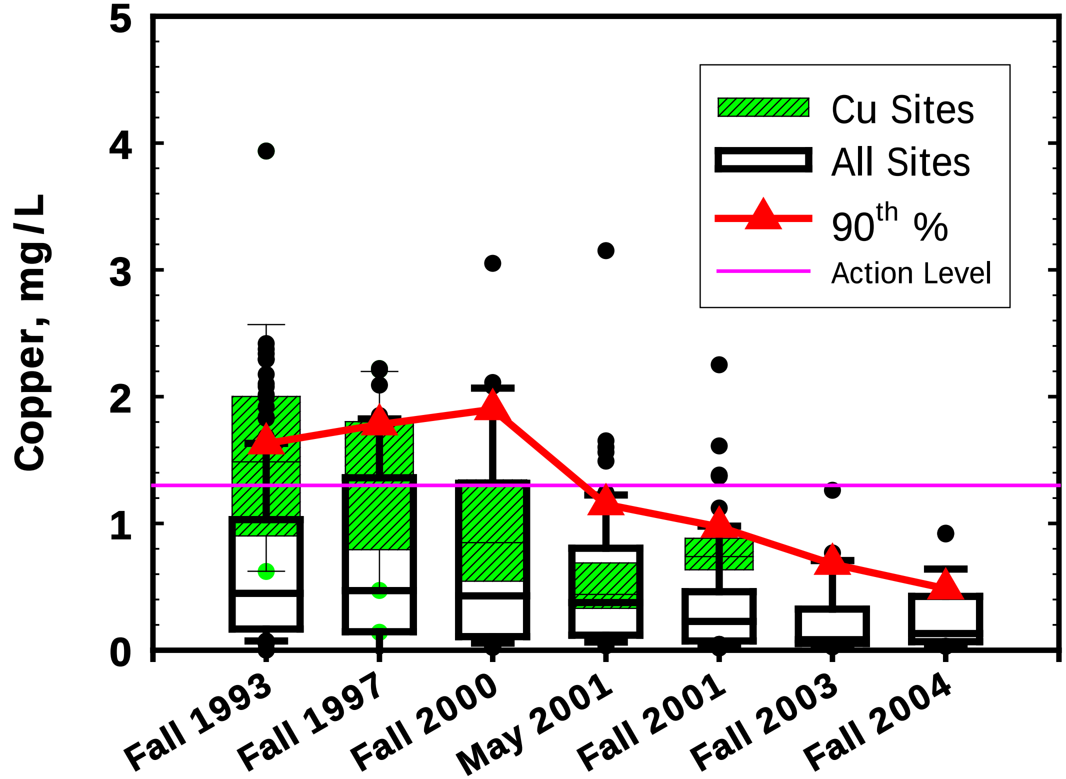
Schock, M. R.; Lytle, D. A.; Clement, J. A. *Effect of pH, DIC, Orthophosphate and Sulfate on Drinking Water Cuprosolvency, EPA/600/R-95/085, 1995.*

- Since the middle 1990s, dozens of international research papers have been published showing the same phenomenon in diverse laboratory and field studies.
- But *only in certain water qualities* will copper release be near or above the **MCLG/AL** from the time of installation.

Cu Aging and LCR Monitoring

DIC = 65 mg C/L Midwest System

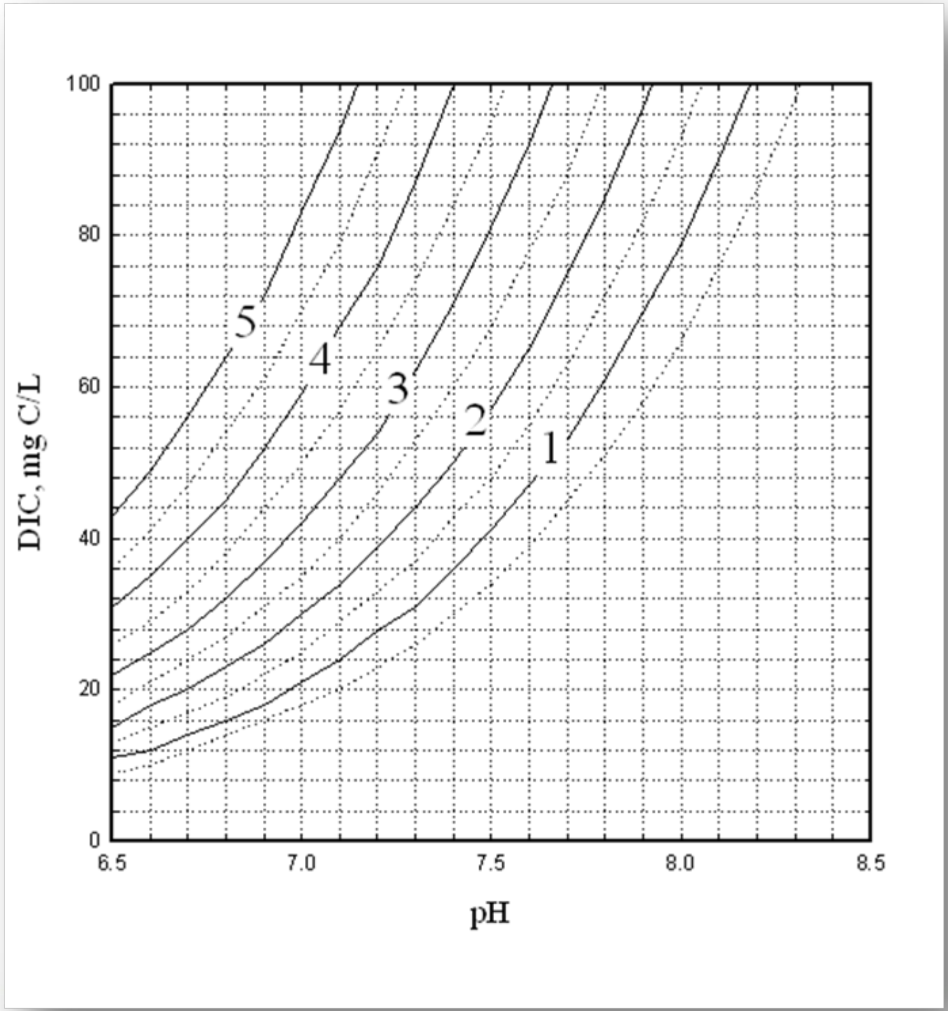
Continually Decreasing 90th Percentile Over Time



OK, meets LCR now *but what about NEW construction*???

Schock, M. R.; Sandvig, A. M. Long-Term Impacts of Orthophosphate Treatment on Copper Levels. *Jour. AWWA* **2009**, 101 (7), 71-82.

Empirical Prediction of Effect of Ortho-P Dose for New Copper



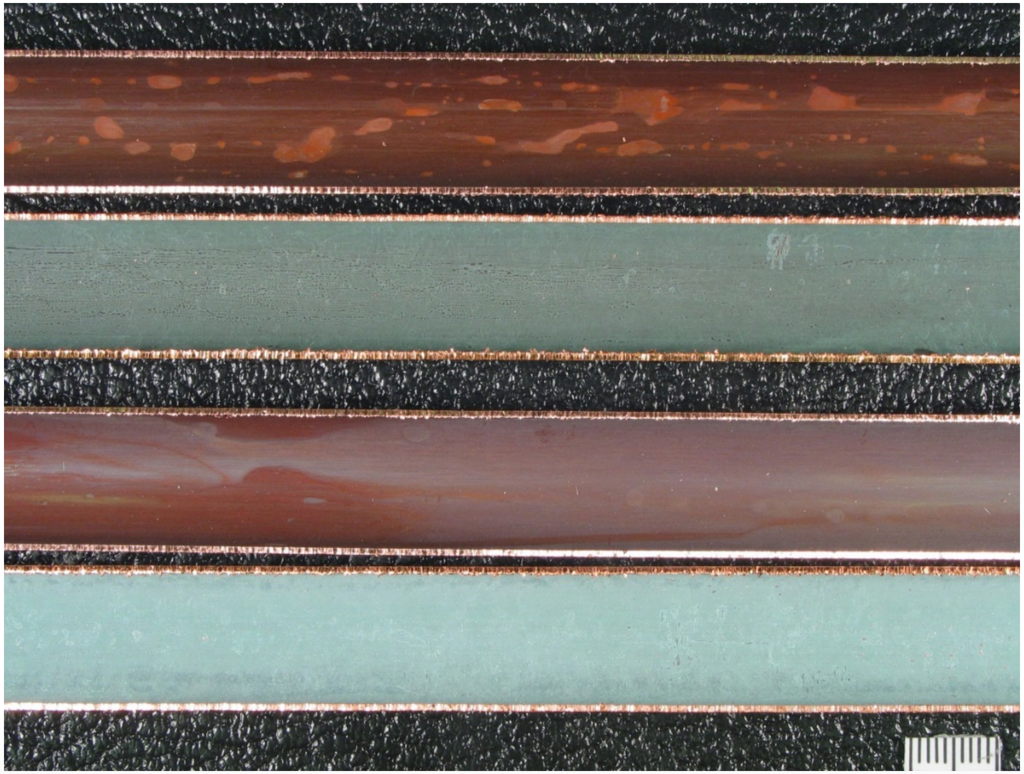
Lytle, D. A.; Schock, M.; Leo, J. The Impact of Orthophosphate on Copper Solubility, *Proc. AWWA Annual Conference*, Denver, CO, June 9-13, **2013**.

Phosphate Inhibits Malachite at High DIC

DIC = 50 mg C/L, PO_4= 3.0 mg/L (upper pipes)

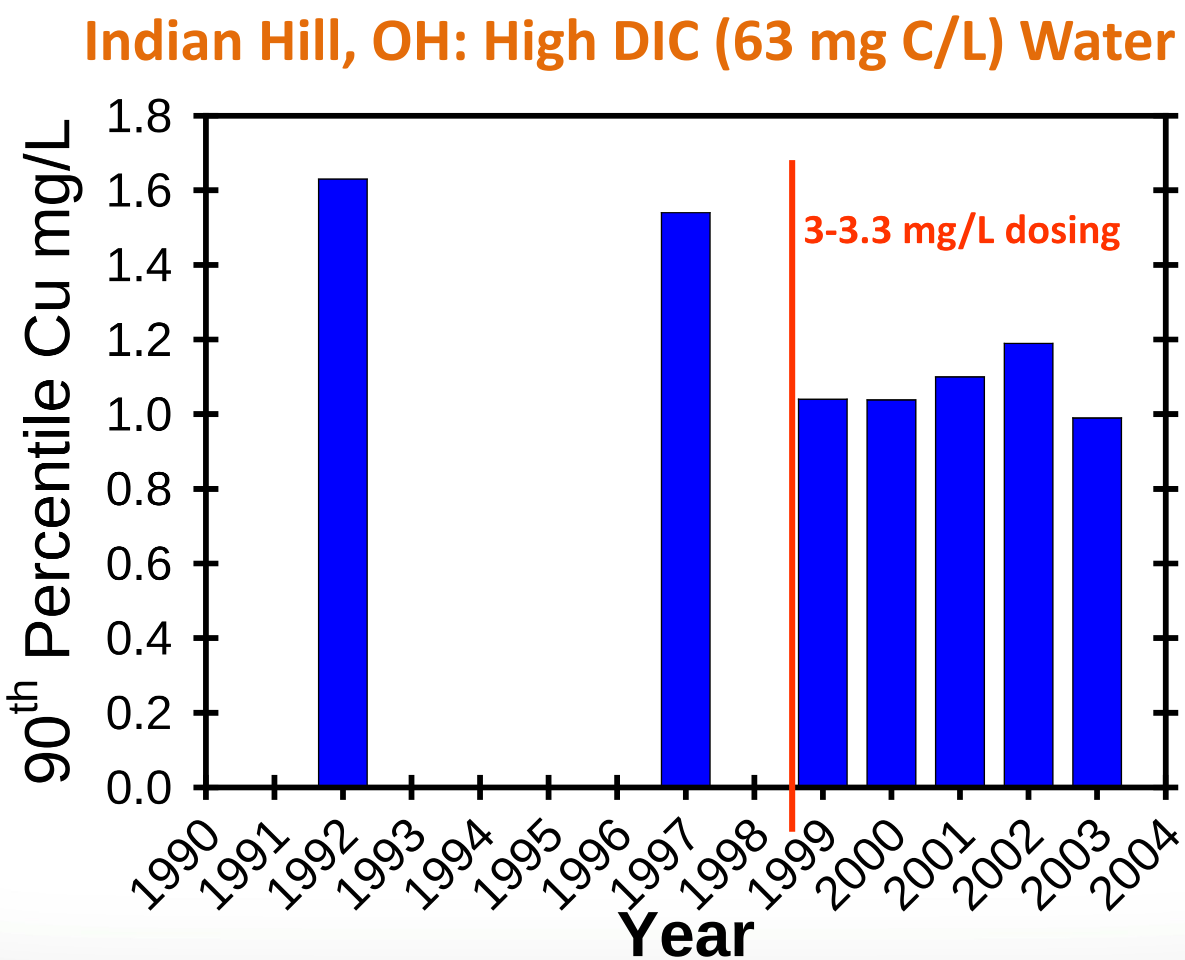
pH 8.0

pH 7.0



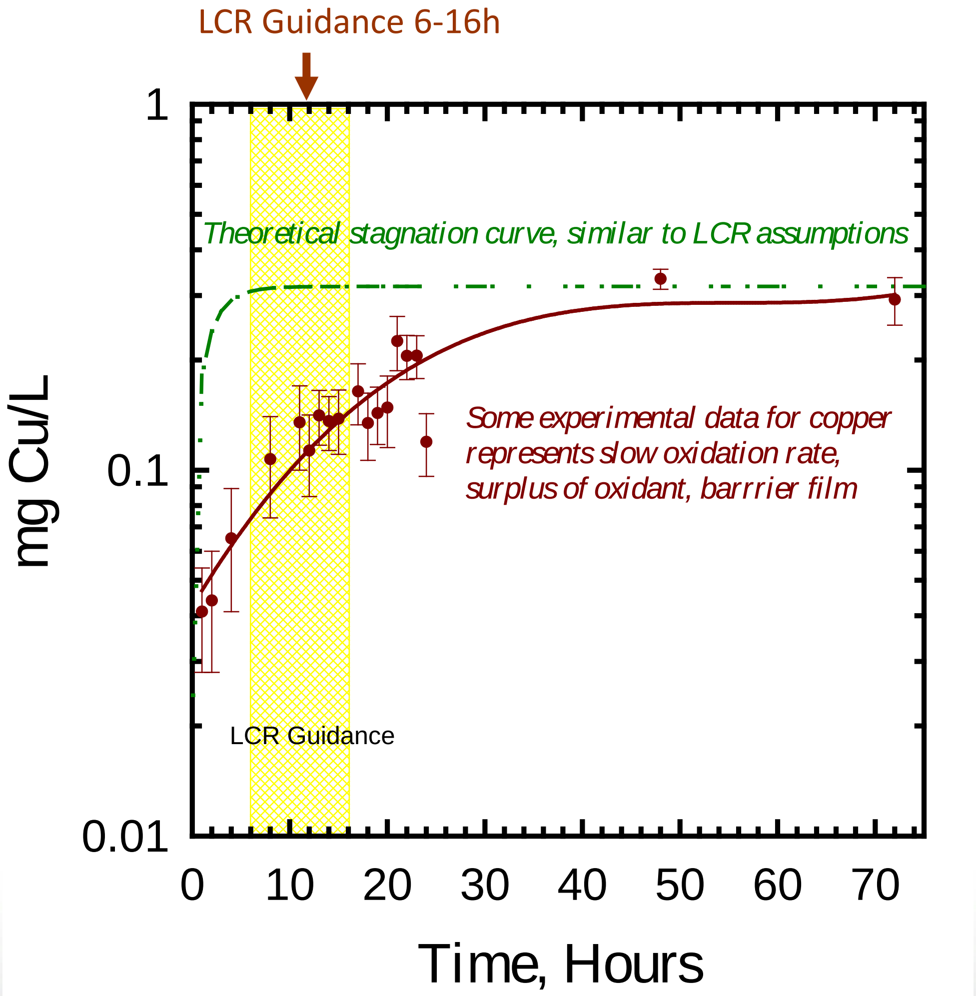
- Tradeoff between short-term health goal and long-term Cu passivation that takes years to decades.
- Aging won't proceed "normally" when orthophosphate is added.
- Enough ortho-P must be added to *immediately* offset elevation of copper by the carbonate level for new plumbing

Consistency of Cu with Enough PO_4



Schock, M. R.; Sandvig, A. M. Long-Term Impacts of Orthophosphate Treatment on Copper Levels. *Jour. AWWA* **2009**, 101 (7), 71-82.

Copper Stagnation Profiles can Increase for Days



Effect of Phosphate Type and Concentration on Cu Release

- Orthophosphate has been shown to *immediately* prevent Cu > MCLG in high alkalinities (over 200 to over 350 mg/L) on new pipe in lab and field studies if dosed at 3.3-3.5 mg/L as PO_4
- Blended phosphates have rarely been shown to reduce Cu below MCLG at high alkalinities, but they *have been shown to perpetuate Cu above the AL*
- Polyphosphates have *not* been successful *unless DIC/pH combination would have worked anyway*
- Phosphates have been shown to be beneficial to *prevent copper pitting* in both low and high alkalinities
- Even orthophosphate at low dosages and low DIC retards or prevents aging, but Cu release not an issue in DW because of high MCLG.
- For systems without LSLs, Pb is usually reduced below the AL at *lower* phosphate dosages than Cu. So, Pb control *should not be the basis for exemptions* from Cu treatment.

Lead and Copper Treatment Summary

System-Wide Optimization

Essential Tool for Simultaneous Compliance

- Requires addressing all direct and indirect factors causing metal release from the plant through the distribution system.
- Requires treating and solving source of conflict, rather than Band-Aid on symptoms, e.g.
  - DBP precursor removal vs. chloramination
  - Iron/Manganese removal vs. sequestration
  - Operational issues, such as waste discharge constraints resulting in too many IX regeneration cycles
- Anticipate and plan for secondary impacts or synergisms of process additions or changes

Some Frequent Situations to Watch with Treatment Changes

- Small system with multiple contaminants (U, As, Rn) using anion-exchange
- Substantial changes in treatment/WQ introduced into old DS
- Disinfection with high ammonia groundwater
- Addition of oxygen or chlorine to high alkalinity ground water with low natural ORP
- Replacing lime softening with IX softening
- Overdosing of polyphosphate to prevent post-deposition of calcium carbonate
- pH reductions to “maximize” IX or sorptive media run lengths or bed lifetimes

OCCT/Lead Control Pilot Studies

- PWS must conduct a proper study to look at what is going on in their pipes for their specific water quality zones in DS
- Optimize under the current operating conditions
- New studies needed well in advance of future treatment or operational changes that could impact lead or copper release. May take years.
- New studies needed to anticipate other DS metal or radionuclide release side effects of changes
- This is *SAME concept* as use of jar tests for coagulation, column tests for filter media evaluation, column tests for As removal, pilot tests for ozonation or UV, etc.

Simultaneous Compliance *IS* Possible

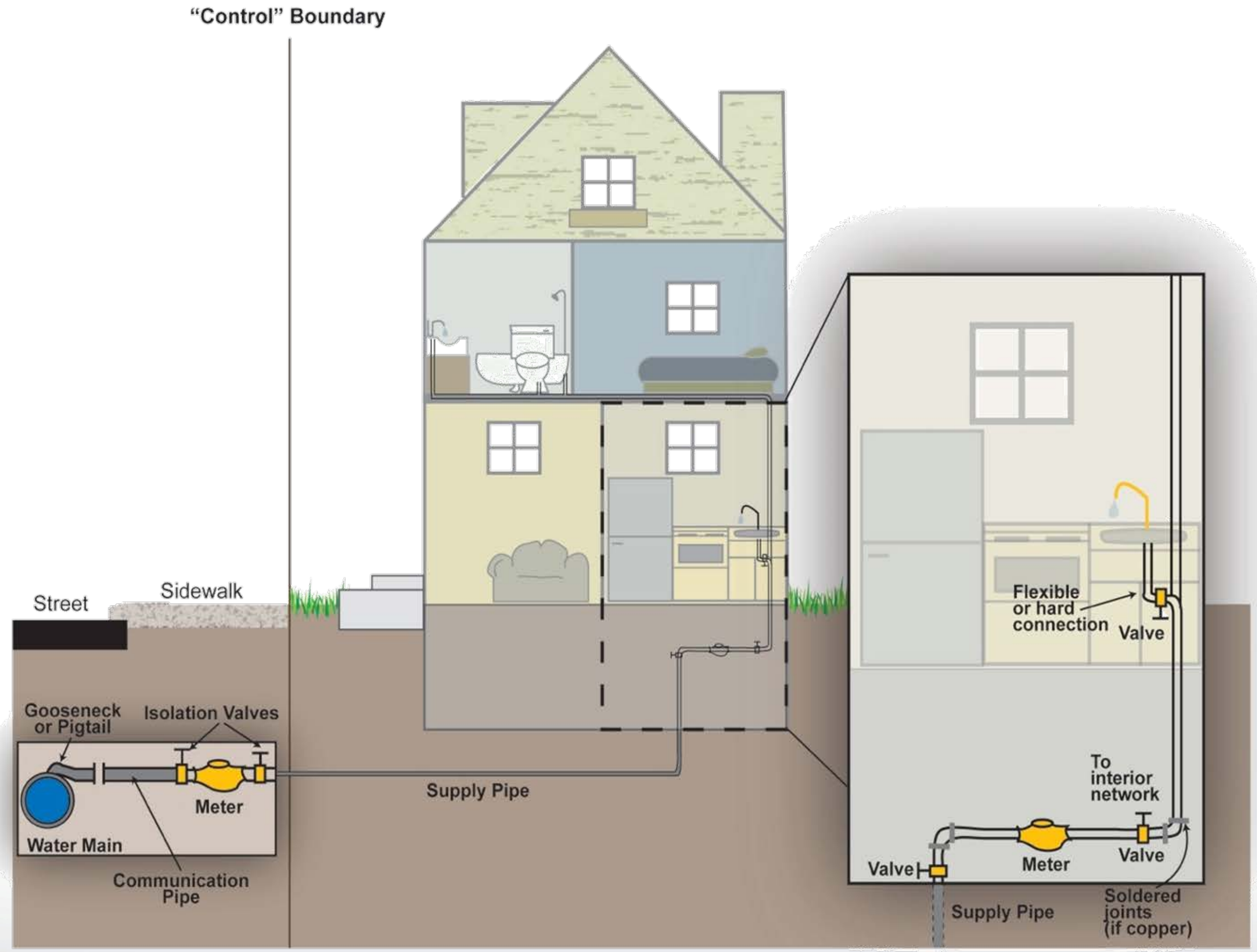
- Recognition of diverse DS WQ relationships
- Recognition of DS and premise plumbing materials
- Commitment to address sources of chemical conflicts, e.g.
  - Removal of interfering substances to metal release
  - DBP precursors
  - Lead sources (notably LSLs)
- Holistic design and integration of processes
- Homogenization of WQ across zones in system to extent possible
- Resources to take actions necessary for O&M of plants and DS
- Necessity of pilot studies to tailor to conditions

Metal Release from Copper & Lead Sources

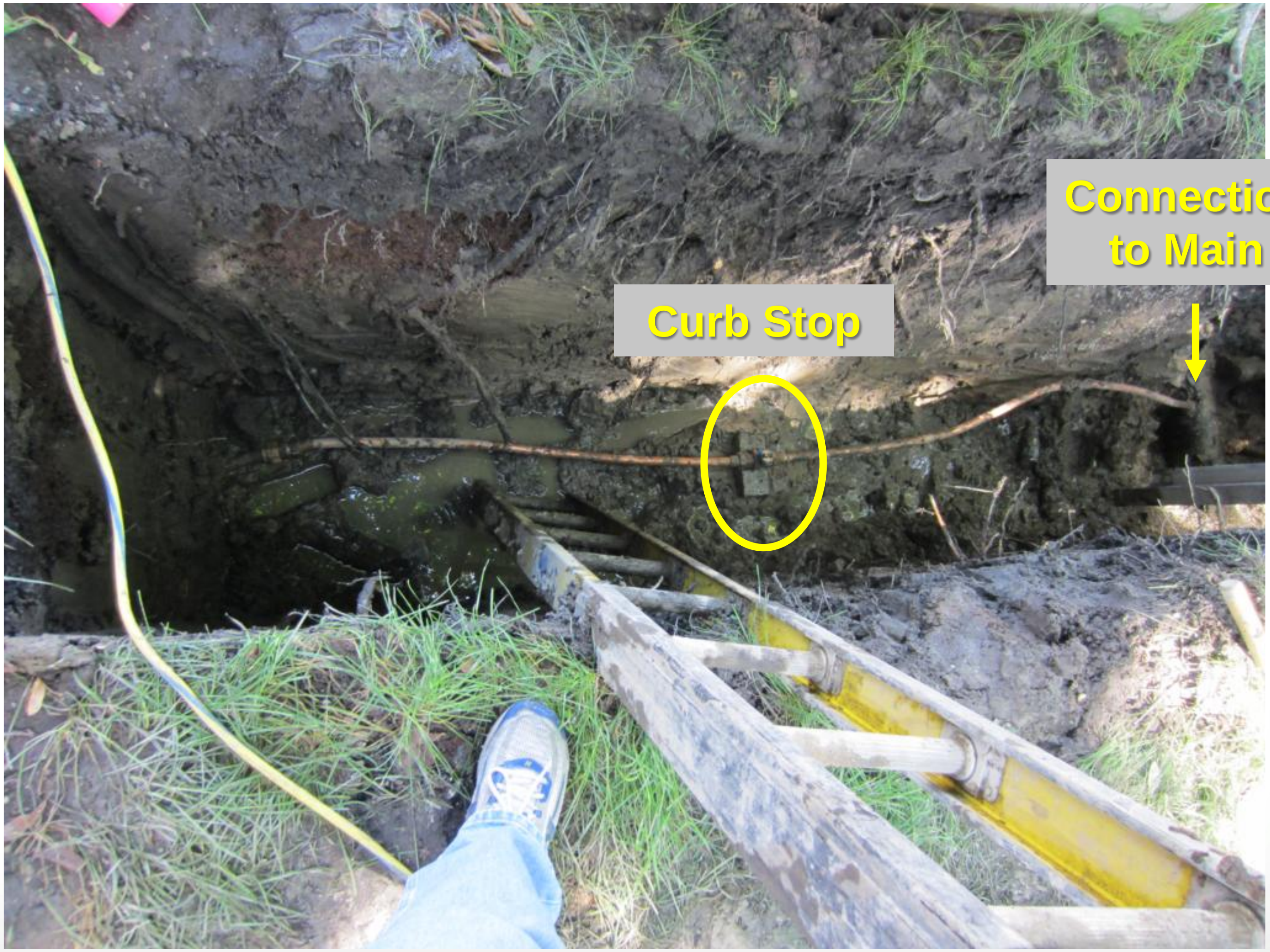
Characteristics of Pb and Cu Sources

- When present, LSL is biggest reservoir of Pb, but may not always be highest spike or peak value
  - Dislodged particles
  - PbO_2-LSL scale systems may have higher Pb from brass fixtures and fittings
- Pb sources within housing and buildings
  - Numerous hidden locations (behind walls, under floors, etc.)
  - Small lateral extent in each occurrence
  - May be located considerably distance from consumption tap
- Sampling instruction details matter
  - Random use pattern presumed by LCR
  - Pre-flushing all but eliminates detecting LSL contribution
  - Water use *prohibited from tap* is different from
  - Water use *prohibited from house/feed line*
- Few sources of Cu, and they are generally more uniform

Typical Household Pb Sources



Main Connection through Curb Stop



Lead Sources are Often Hidden

Valves are Often Overlooked when Focus is on Faucets

- Shut-off valves frequently are captured in 250 mL to 1 L samples
- Often not certified ANSI/NSF Section 9

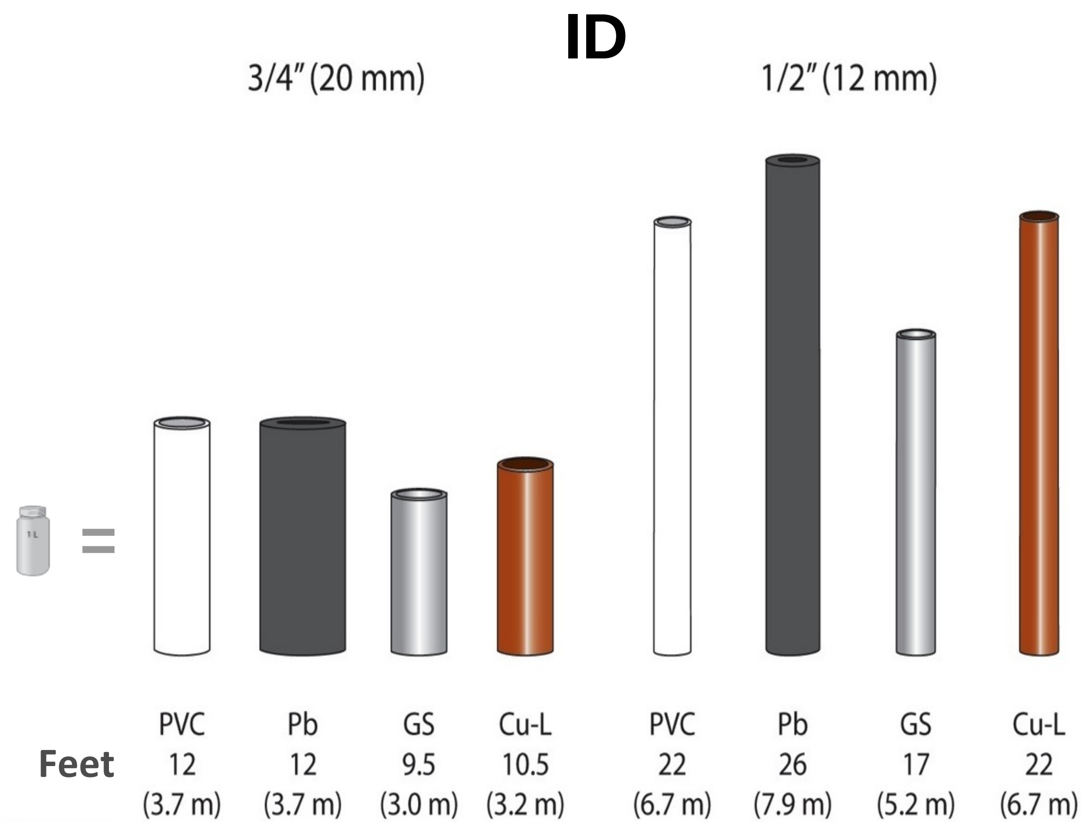
Auto-Mixing Valves: New and Growing Confusing Source

More institutions are using automatic mixing faucets that blend hot and cold water as ONLY outlet for potable water dispensing

Sampling to Identify Lead Sources

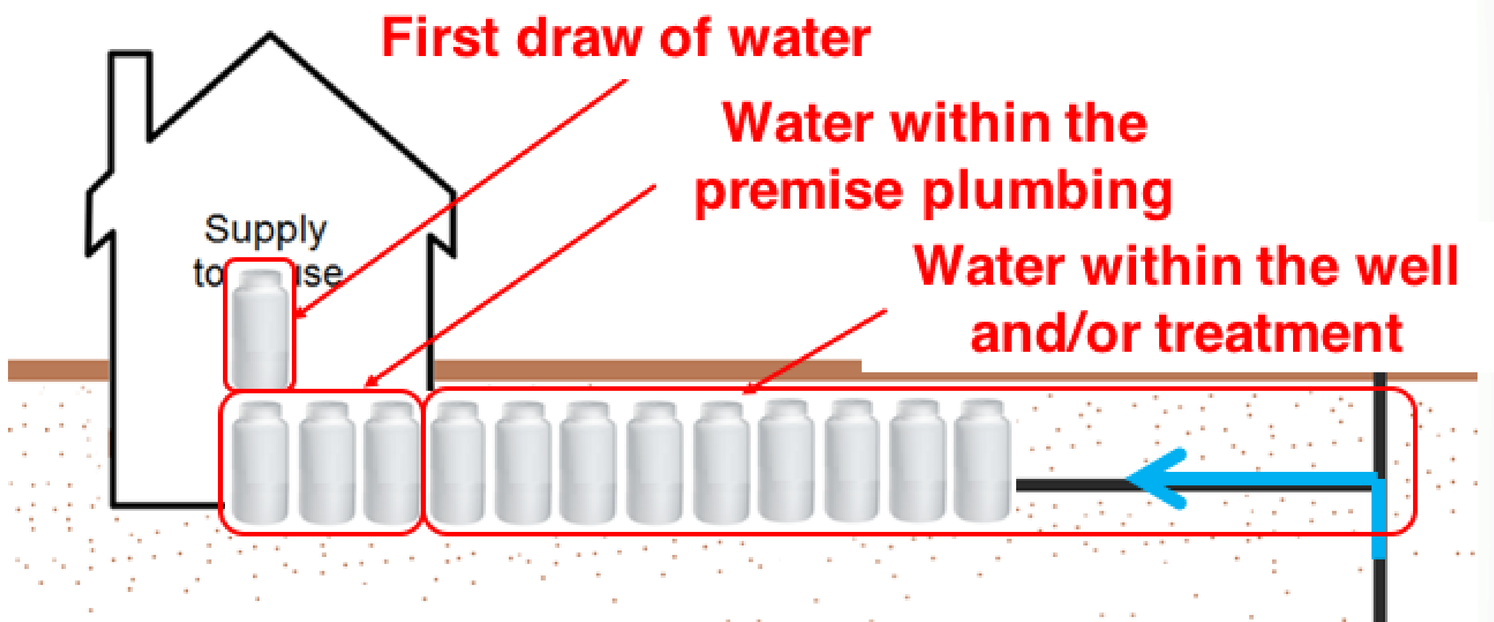
Tool: Sample Volumes Represent Source Position in Plumbing

Wide-mouth bottles preferable to allow higher flow rate



After: Schock, M. R.; Lytle, D. A. Internal Corrosion and Deposition Control; In *Water Quality and Treatment: A Handbook of Community Water Supplies*; Sixth ed. 2011.

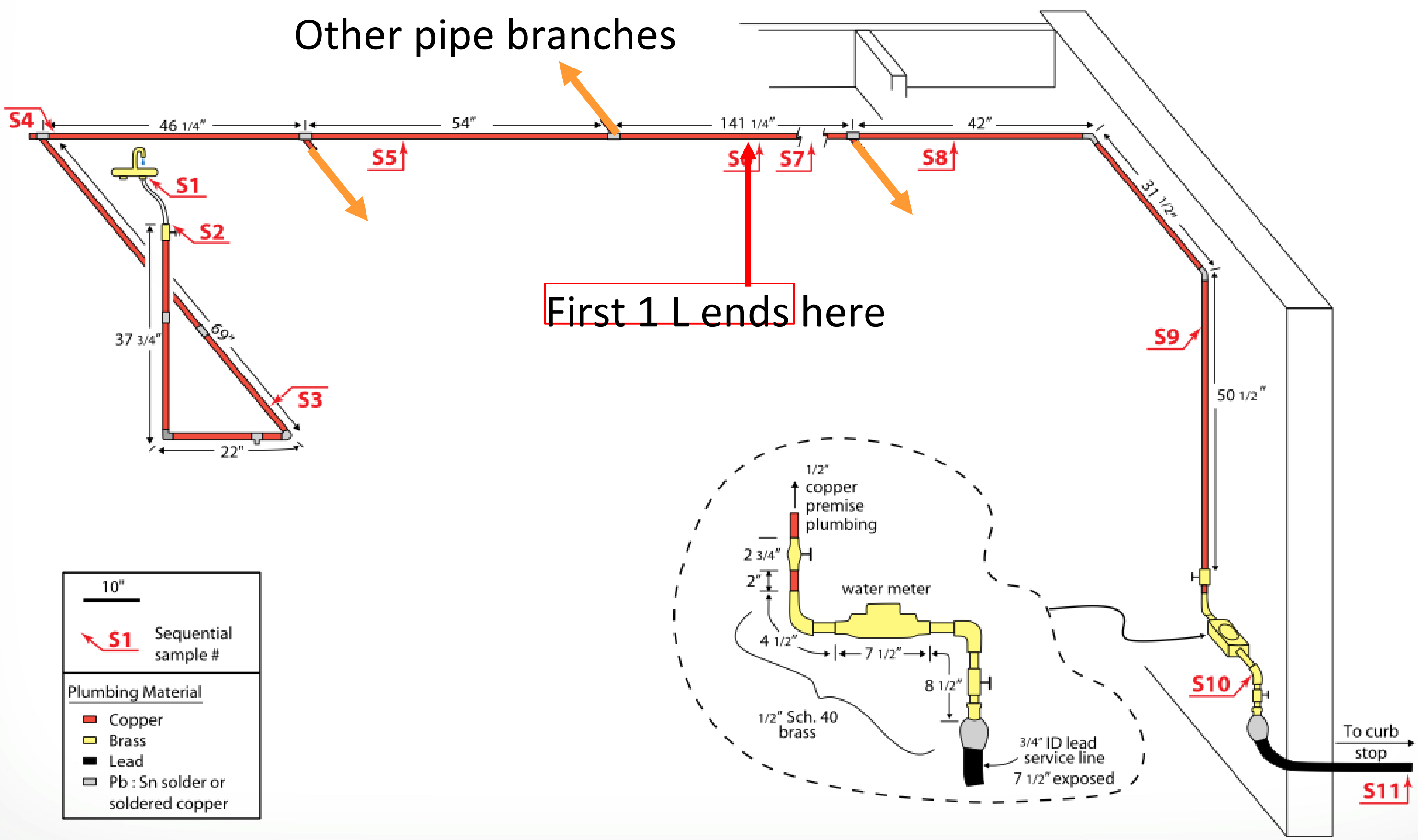
Concept of Sequential Sampling (aka “profiling”)



- Visually inspected the plumbing network
  - Estimate volumes of water within piping sections
- Samples collected from cold-water kitchen tap

Courtesy: Kelsey Pieper, UNC

Identifying Pb Sources in a House: Volume as Distance



Sample Volume per Length: Cu

Material	Type	Nominal Size (in)	OD (in)	Thickness (in)	ID (in)	mL/ft	mL/m	ft per L	m per L
Copper tube	K	0.500	0.625	0.049	0.527	43	141	23.3	7.1
Copper tube	L	0.500	0.625	0.04	0.545	46	151	21.8	6.6
Copper tube	M	0.500	0.625	0.028	0.569	50	164	20.0	6.1
Copper tube	K	0.750	0.875	0.065	0.745	86	281	11.7	3.6
Copper tube	L	0.750	0.875	0.045	0.785	95	312	10.5	3.2
Copper tube	M	0.750	0.875	0.032	0.811	102	333	9.8	3.0
Copper tube	K	1.000	1.125	0.065	0.995	153	502	6.5	2.0
Copper tube	L	1.000	1.125	0.05	1.025	162	532	6.2	1.9
Copper tube	M	1.000	1.125	0.035	1.055	172	564	5.8	1.8

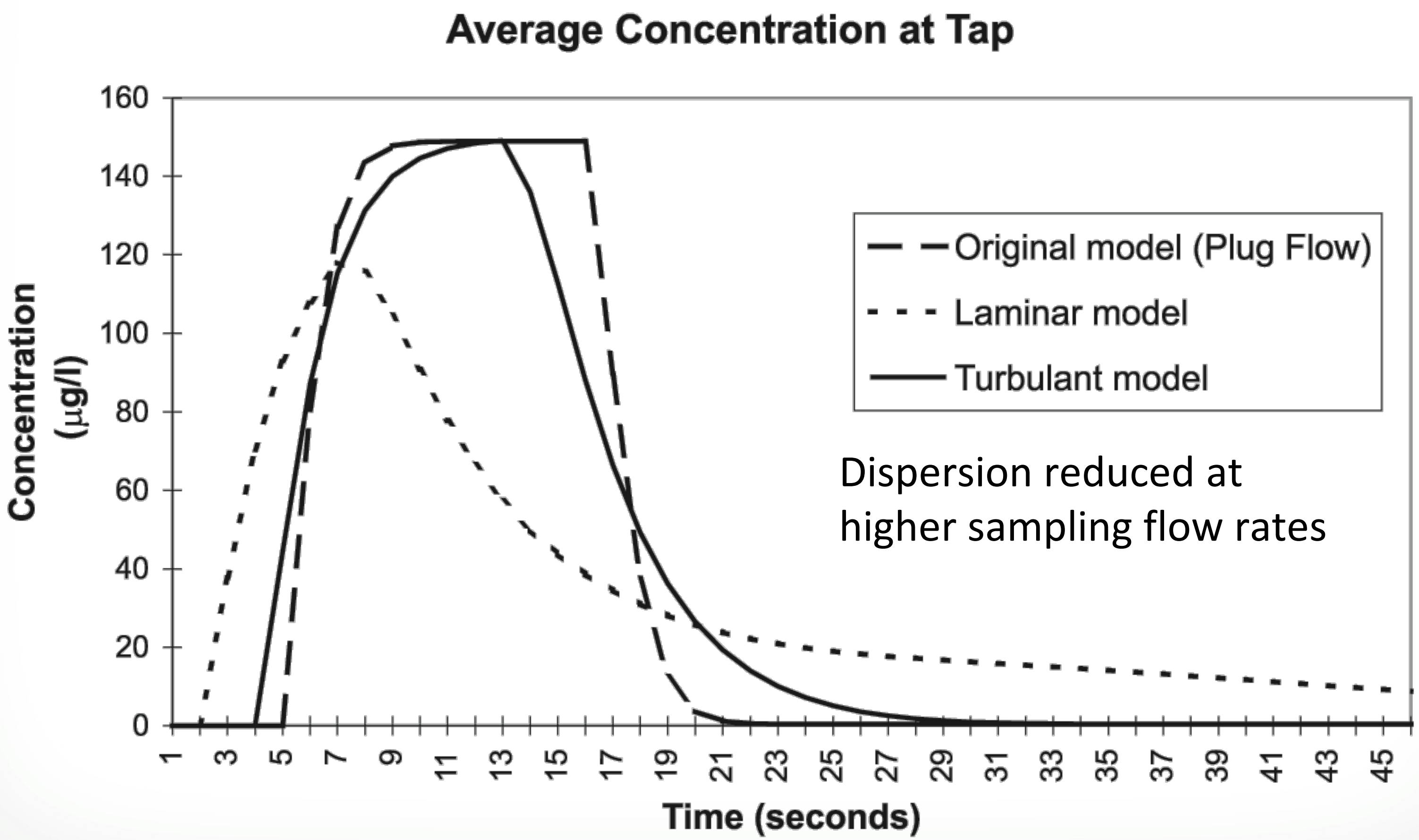
Example: ¾-in ID Type L Copper

Material	Type	Nominal Size (in)	OD (in)	Thickness (in)	ID (in)	mL/ft	mL/m	ft per L	m per L
Copper tube	K	0.500	0.625	0.049	0.527	43	141	23.3	7.1
Copper tube	L	0.500	0.625	0.04	0.545	46	151	21.8	6.6
Copper tube	M	0.500	0.625	0.028	0.569	50	164	20.0	6.1
Copper tube	K	0.750	0.875	0.065	0.745	86	281	11.7	3.6
Copper tube	**L**	**0.750**	0.875	0.045	0.785	**95**	**312**	**10.5**	**3.2**
Copper tube	M	0.750	0.875	0.032	0.811	102	333	9.8	3.0
Copper tube	K	1.000	1.125	0.065	0.995	153	502	6.5	2.0
Copper tube	L	1.000	1.125	0.05	1.025	162	532	6.2	1.9
Copper tube	M	1.000	1.125	0.035	1.055	172	564	5.8	1.8

Sample Volume/Length (other)

Material	Type	Nominal Size (in)	OD (in)	Thickness (in)	ID (in)	mL/ft	mL/m	ft per L	m per L
Galvanized steel	Sched 40	0.500	0.840	0.109	0.622	60	196	16.7	5.1
Galvanized steel	Sched 40	0.750	1.050	0.113	0.824	105	344	9.5	2.9
Galvanized steel	Sched 40	1.000	1.315	0.133	1.049	170	558	5.9	1.8
Lead	0.25-in wall	0.500	1.000	0.25	0.500	39	127	25.9	7.9
Lead	0.25-in wall	0.625	1.125	0.25	0.625	60	198	16.6	5.1
Lead	0.25-in wall	0.750	1.250	0.25	0.750	87	285	11.5	3.5
PVC, CPVC	Sched 80	0.500	0.84	0.147	0.546	46	151	21.7	6.6
PVC, CPVC	Sched 80	0.75	1.05	0.154	0.742	85	279	11.8	3.6
PVC, CPVC	Sched 80	1	1.315	0.179	0.957	141	464	7.1	2.2
HDPE	200 psi	1	1.315	0.146	1.023	162	530	6.2	1.9

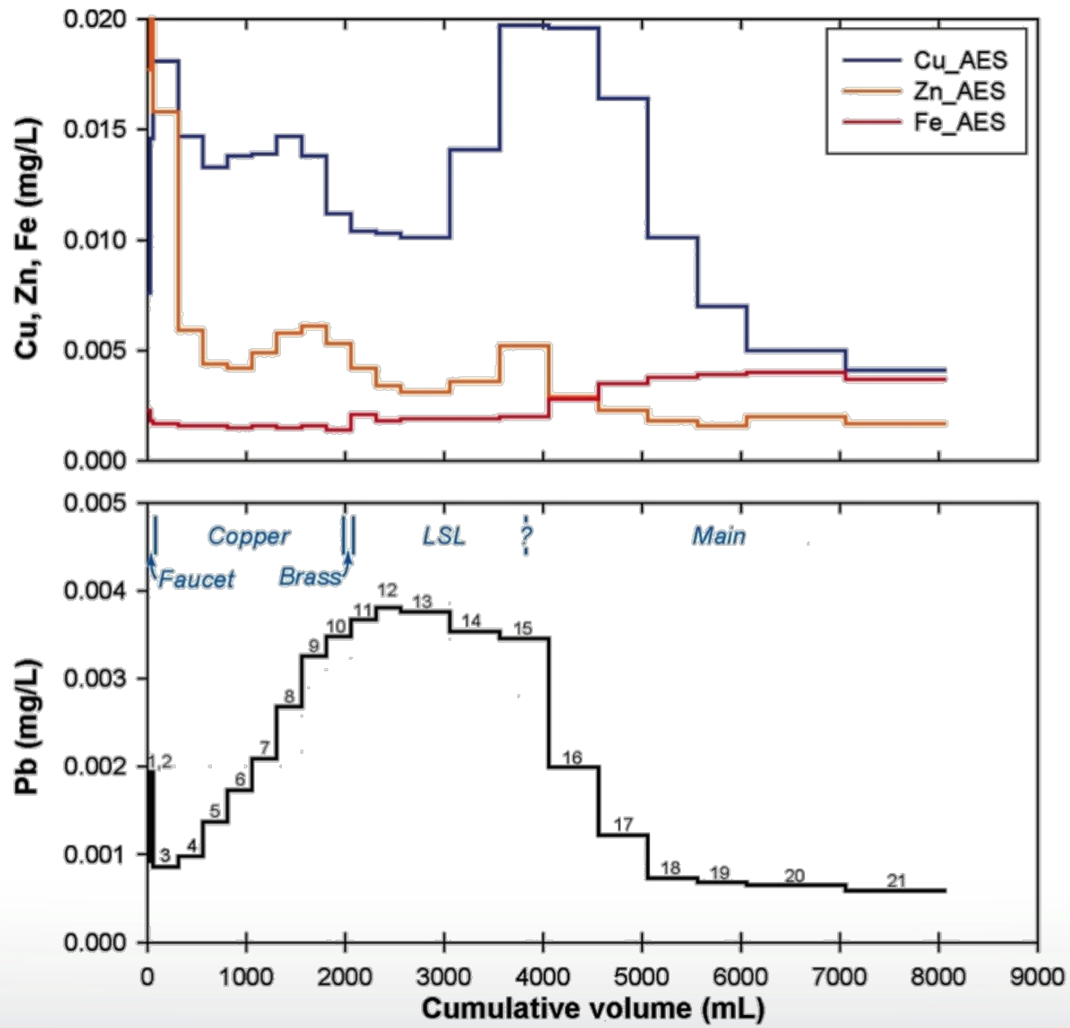
Resolution Depends on Dispersion



From: VanDer Leer et. al. *Applied Mathematical Modelling,* (2002) 26:681–699

Tuberculation and Physical Characteristics Impact Flow

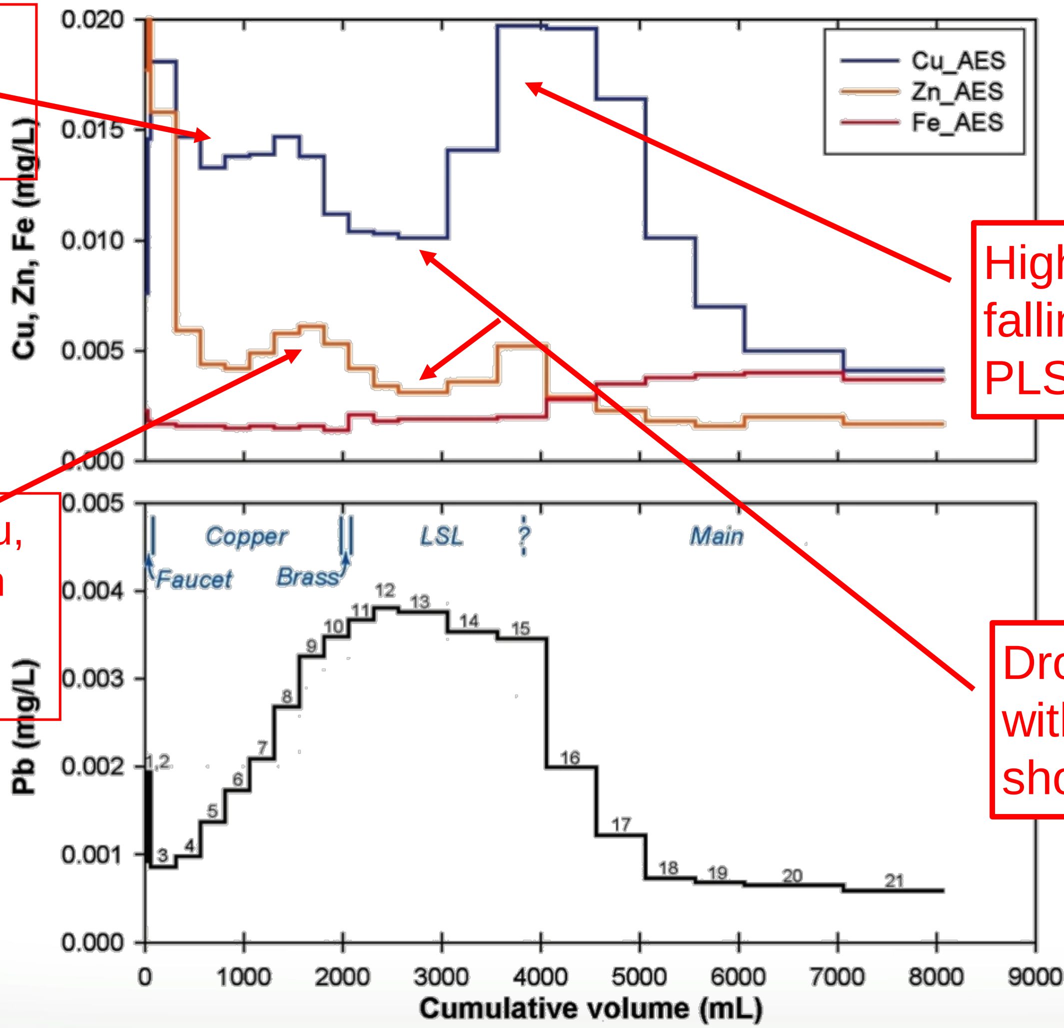
Including Cu, Zn and Fe is very Useful



Including Cu, Zn and Fe is very Useful

Consistent high Cu is interior piping

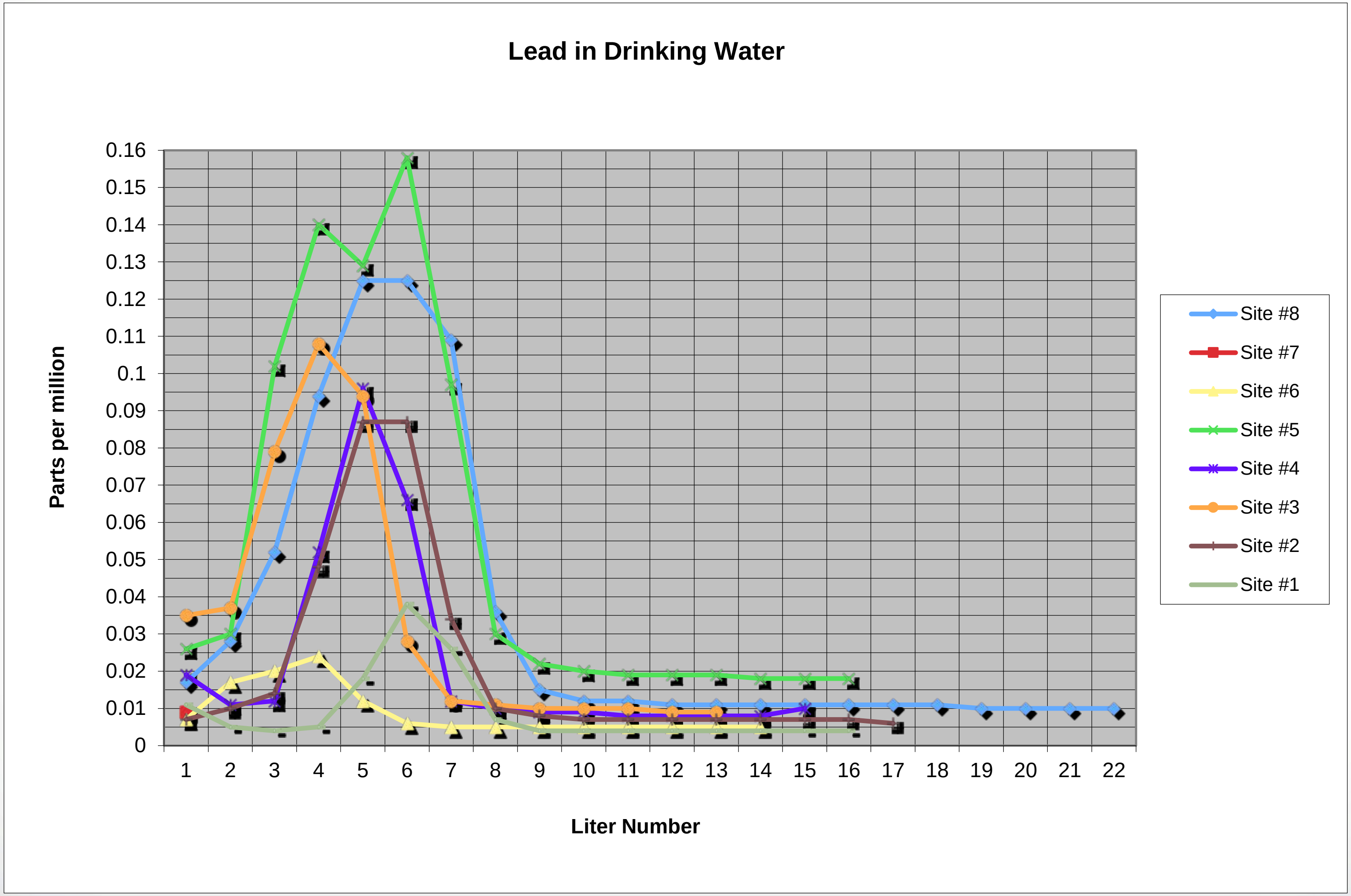
High Zn and Cu, associated with rising Pb is meter area



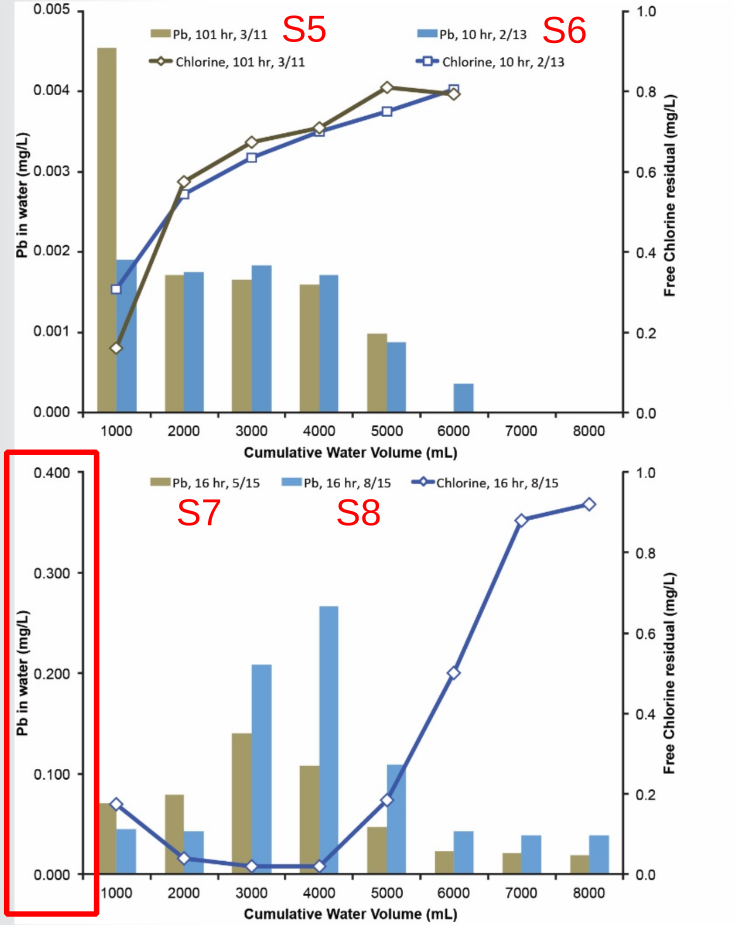
Higher copper with falling lead shows PLSLR

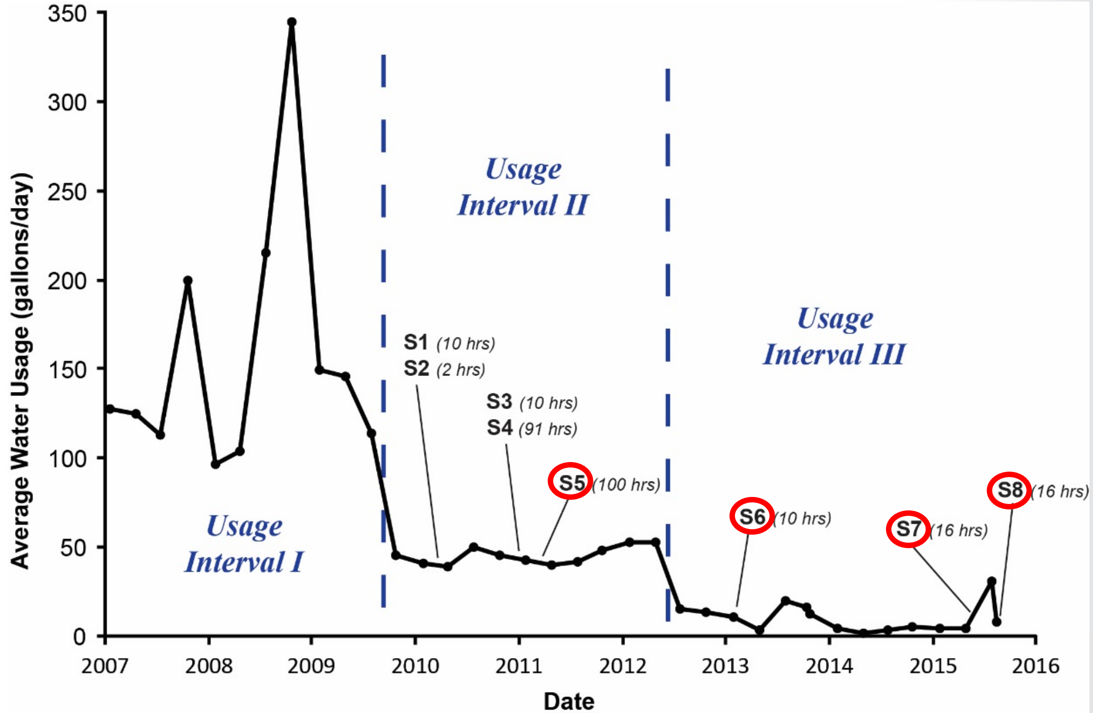
Dropping copper with dropping Zn shows LSL

LSL Profiles, Northeastern City

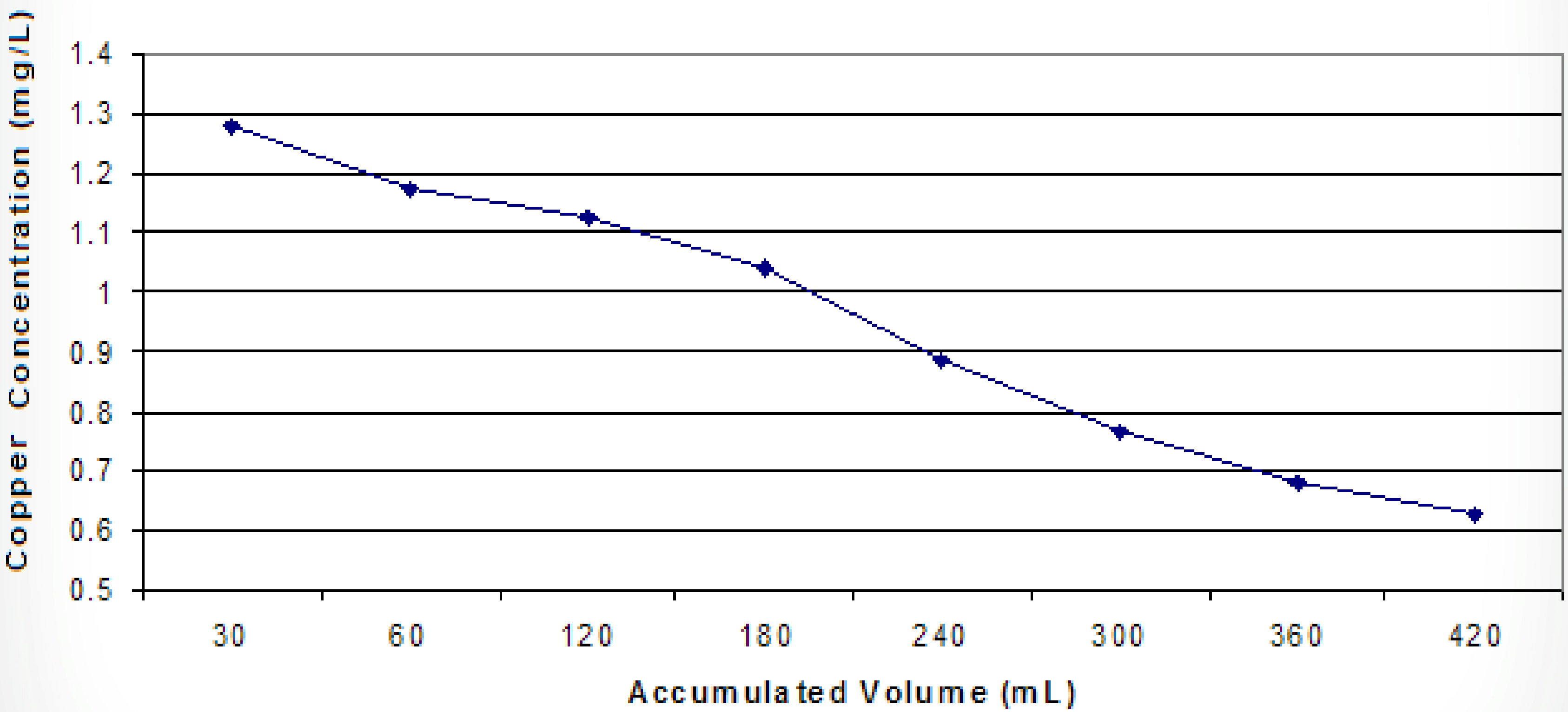


Beware of Vacant House & Low Use





Effect of Renovation (New Cu) at Sink



Potential Constraints of Sequential Sampling

- The farther the deviation from plug flow, the less accurate in finding exact location of specific sources
- The longer the distance of the tap from the source, and the more bends, the more mixing that will take place
  - Lowering peak Pb
  - Loss in resolution
  - May displace precise peak positions relative to source locations
- Samples can be biased by water passing through leaded devices on the way to the bottle
- Accurately capturing particulate release highly depends on on-off protocol, flow rate and flow turbulence

Solving the Problem with Replacement

Why Not Install Treatment?

- Cost and complexity of staffing and certifying licensed operators
- Cost and complexity of treatment, pressurization, storage
- Chemical handling and safety issues
- Cost of ongoing monitoring
- Does not address accumulation of contaminants in plumbing
- No "representative" taps: Exposure risk usually varies from tap to tap and with different water outlets
- SDWA sampling framework for LCR (and other regulations) based on municipal kinds of distribution system, not buildings
- Water usage pattern not usually like residential housing, may not be able to prevent metal release by treatment under extreme conditions
- **Solve problem permanently, no concern needed about future system treatment or water quality changes**

Solutions for High Lead

Lead Sources	First Preference	Second Preference
Lead service line present	Replace with plastic piping	Replace with copper but use dielectric coupling
Leaded brass fixtures or fittings	Replace with NSF/ANSI 61-certified endpoint AND inline devices	[Avoid treatment if at all possible]
Lead:Tin soldered joints	Replace with plastic piping or copper (if suitable water chemistry) with lead-free solder or compression fittings	Need to test for efficacy of modest pH adjustment or ortho-P addition
Lead accumulated in interior plumbing deposits (eg. Mn or Fe-rich scales)	Replace with plastic piping or copper (if suitable water chemistry) with lead-free solder or compression fittings	Install NSF/ANSI 53-certified POU devices

Solutions for High Copper

Water Quality Condition	First Preference	Second Preference
Low pH, low DIC/buffering	Replace with plastic piping	Aeration, “limestone” neutralization
Neutral pH, high DIC	Replace with plastic piping	> 3.3 mg PO_4/L orthophosphate
High pH, low DIC (pitting)	Replace with plastic piping	Add orthophosphate (based on pilot test)

Chemical feed solutions generally require disinfection addition, if not present.

Questions?

Contact

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Disclaimer

This presentation has been reviewed in accordance with U.S. Environmental Protection Agency (EPA) policy and approved for external presentation. The views expressed are those of the author[s] and do not necessarily represent the views or policies of EPA.

Office of Research and Development

EPA Iron Release Research

Darren Lytle

1/26/2016

EPA Iron Research

- Background
- Iron release research
- Iron particle research
- Examination of iron-based pipes
- Accumulation of contaminants in the distribution system

Corrosion vs. Iron Release

Corrosion of iron is the conversion of “metallic iron” to an oxidized form, either soluble or an oxidized scale.

- $Fe \rightarrow Fe^{2+} + 2e^{-}$
- Usually measured as weight loss from metallic iron

Iron release is the transport of iron, in soluble form or as a particle, from corrosion scale or metal to bulk water.

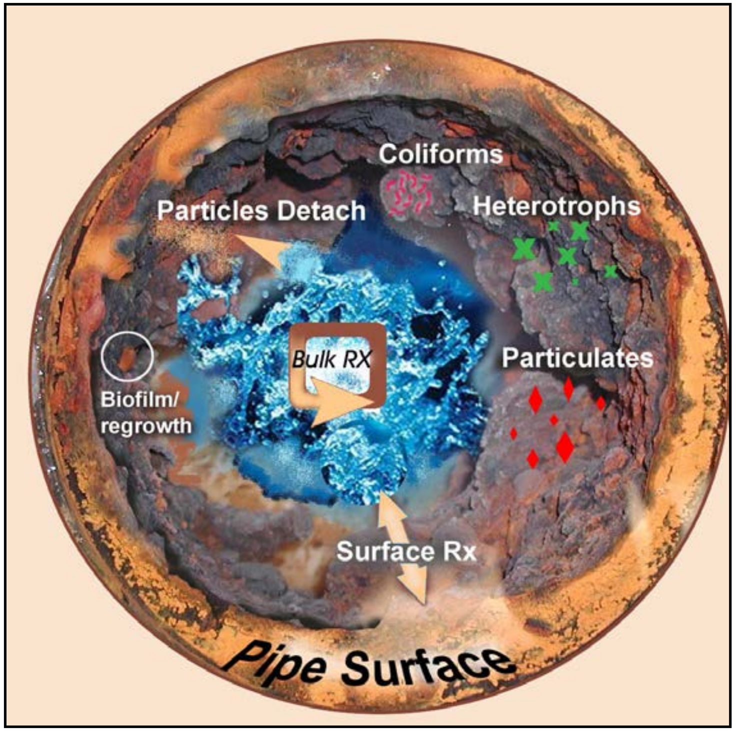
- Cumulative effect of corrosion, hydraulic scouring and dissolution of corrosion scales.
- Usually measured as concentration of iron in bulk water

Effects of Iron Scales & Iron Release

- Particle formation
- Discolored water
- Staining of fixtures, clothing
- Metallic tasting water
- Flow restriction
- Oxidant demand
- Biofilm

Complexity of Iron Release

Distribution System is a Large Reactor



"Red Water" Formation

Iron Release from Corrosion Scales

-Flow Velocity
-Flow Direction
-Disturbances

-Corrosion
-Dissolution
-Reduction
-Water Chemistry

-Reduction
-Dissolution
-Solubility

-Dissolution of By- product other than Fe
-Particle Stability

Physical

-Abrasion
-Erosion

Chemical

-Water Chemistry

Fe^{2+}

-Oxidation
-Water Chemistry

Nucleation

Biological

-Water Chemistry

Indirect Chemical

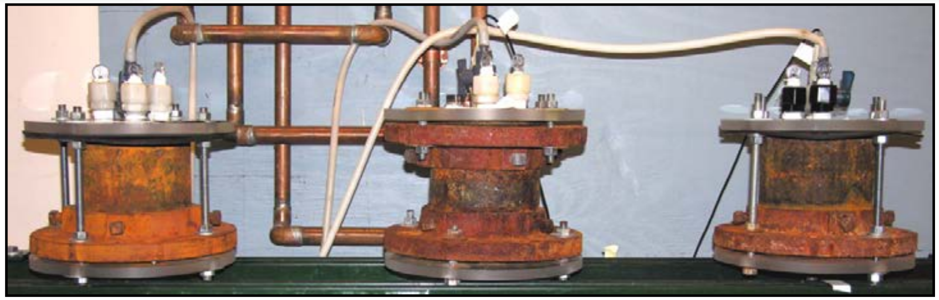
-Particle Stabilization
-Scale Breakdown
-Water

Fe^{3+} Particle

"Red Water" Appearance

Multi-Discipline Research Approach

Large pilot studies



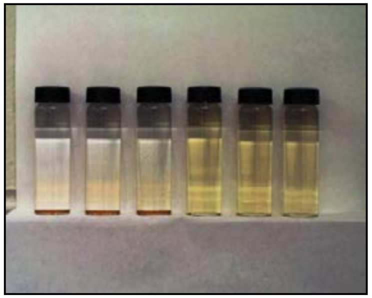
Bench-scale studies

Solids analysis

Corrosion by-product

Full-scale studies

Batch precipitation studies

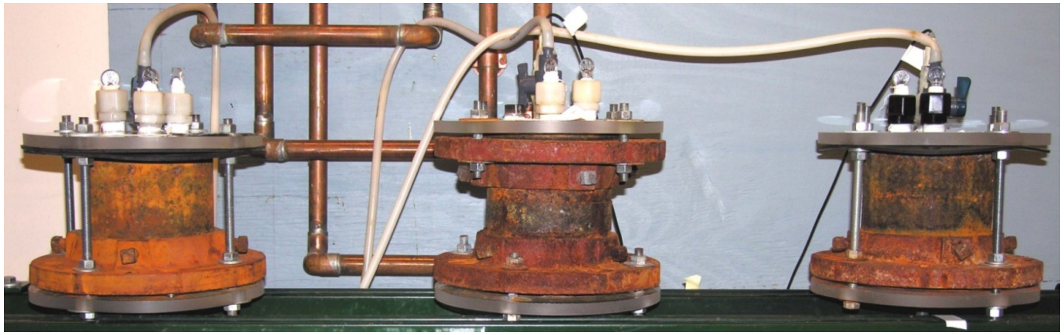


Iron particle studies

Biofilm

Iron Release Research

Iron Pipe Study

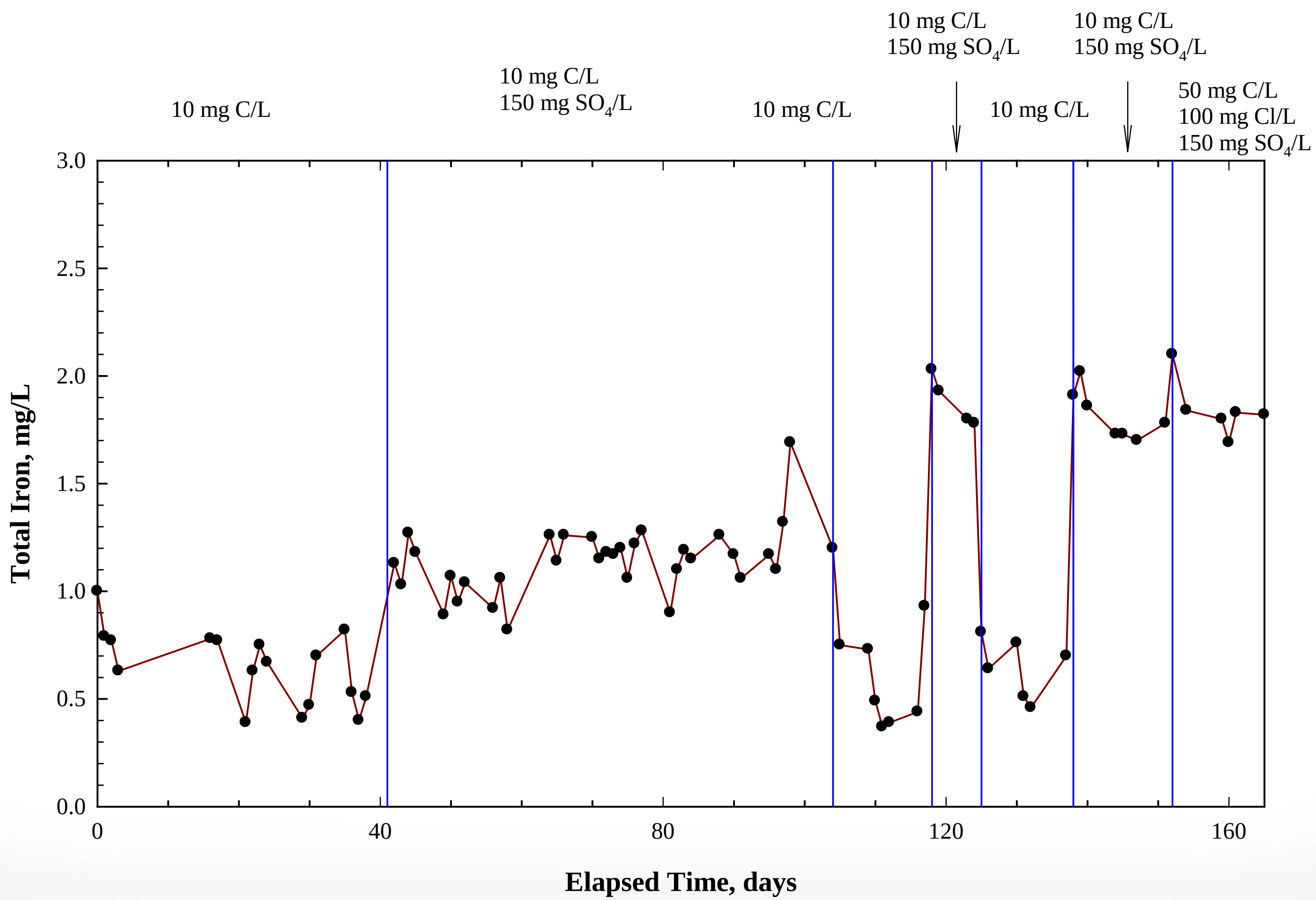


90 year old cast iron pipe section from CWW

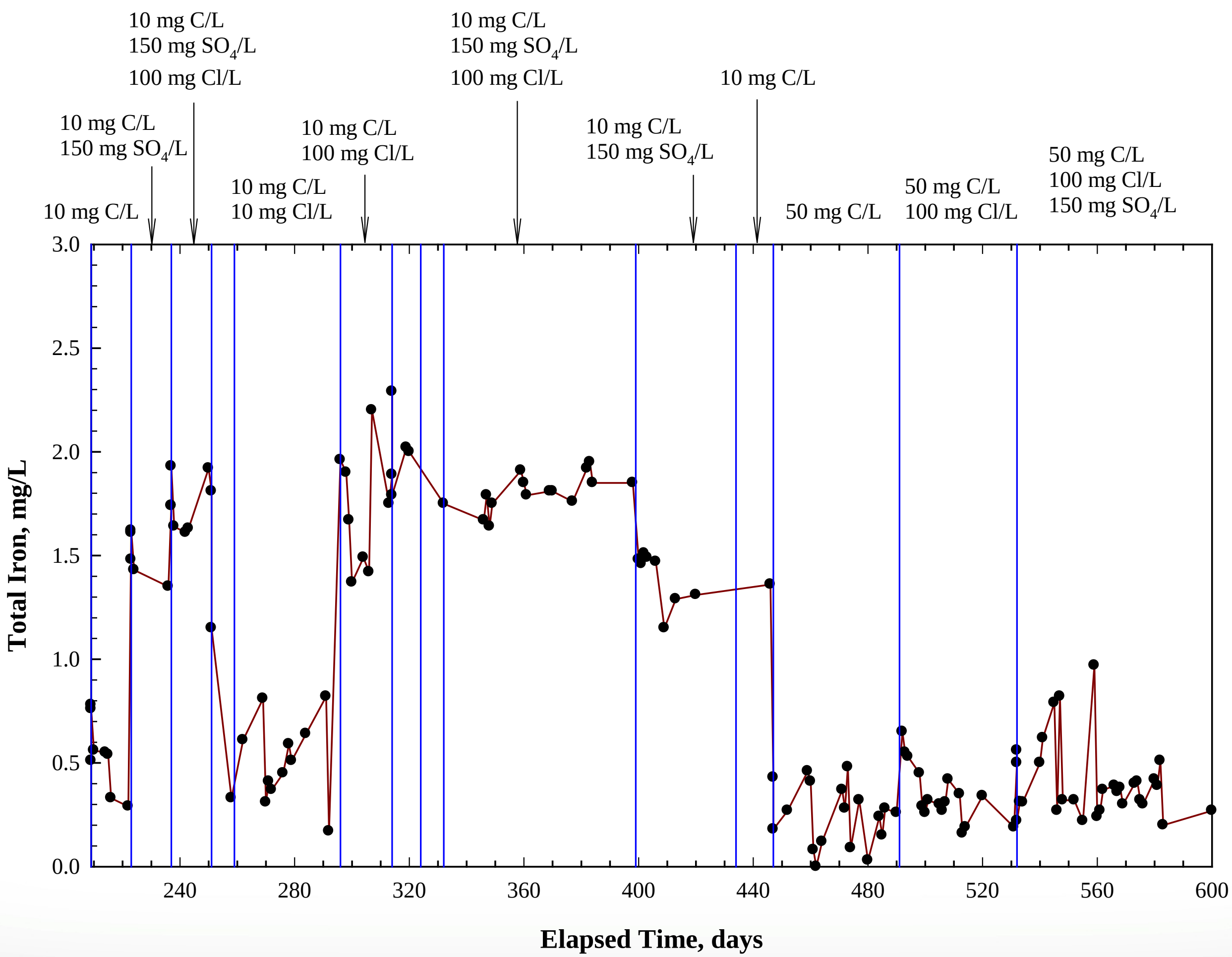
Experimental

- 90 year old cast iron pipe section (volume, diameter)
- Sample from center of pipe after 23.5 hours stagnation (72 hrs)
- Measure REDOX, pH, DO, iron, metals (ICAP)
- Slowly fill with adjusted deionized water (2 liters)
- pH 8, DIC 10 and 50 mg C/L, 0 and 150 mg SO_4/L, and 0 and 100 mg Cl/L

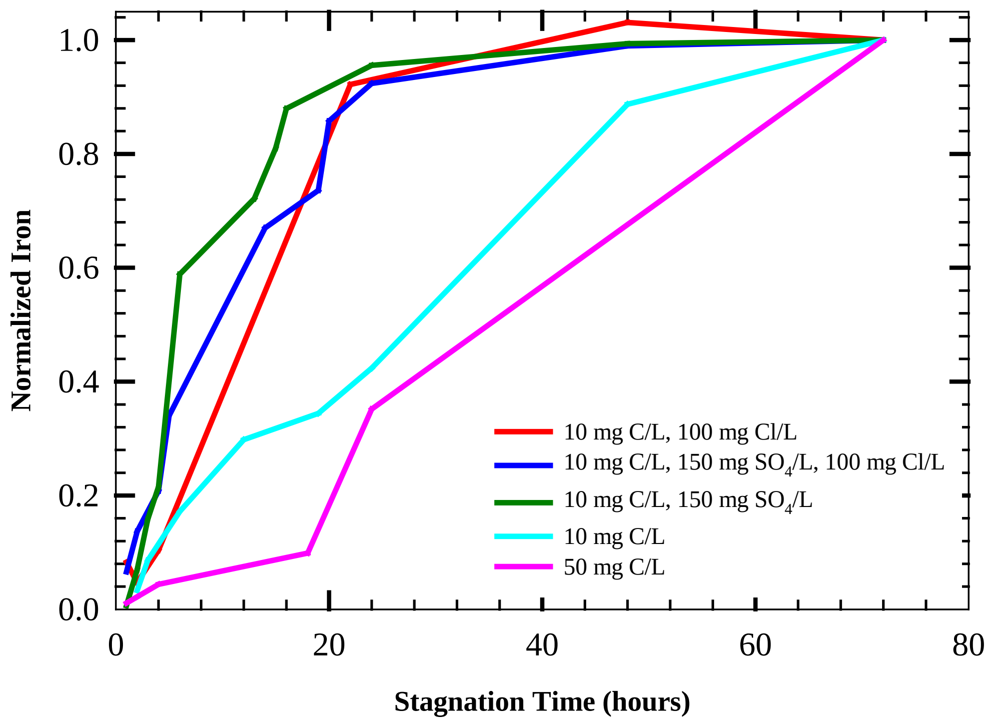
Iron Release



Iron Release (continued)



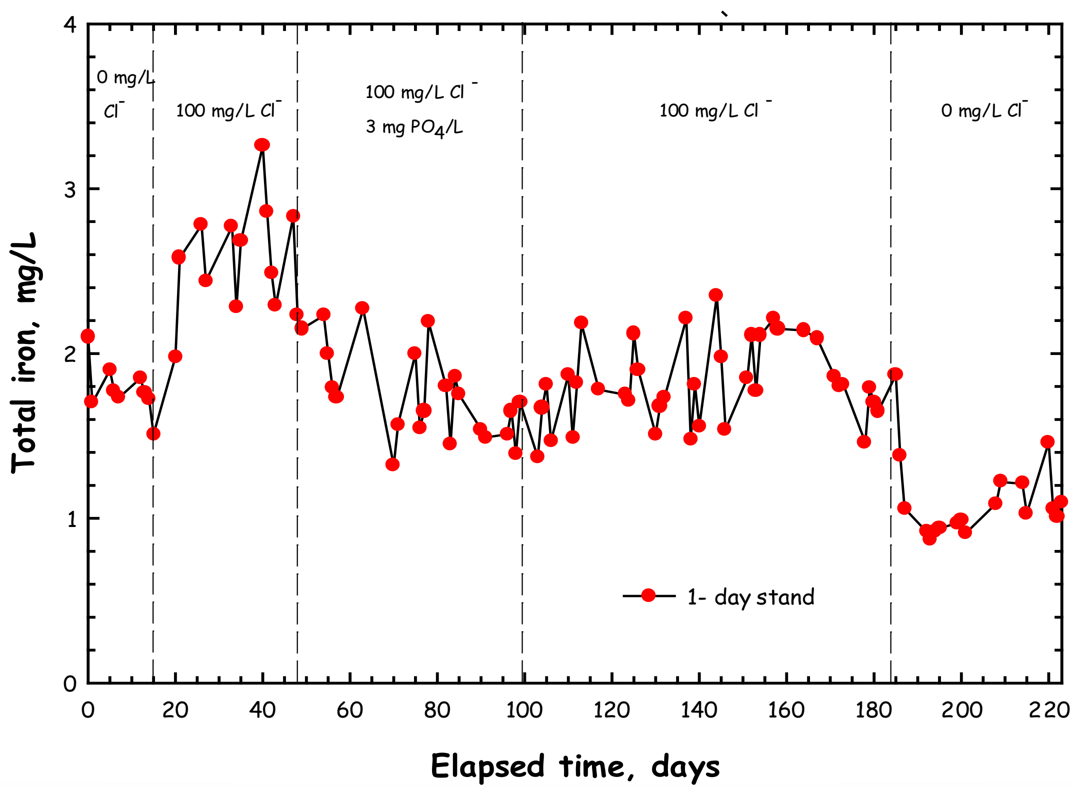
Normalized Iron Release Stagnation Profile



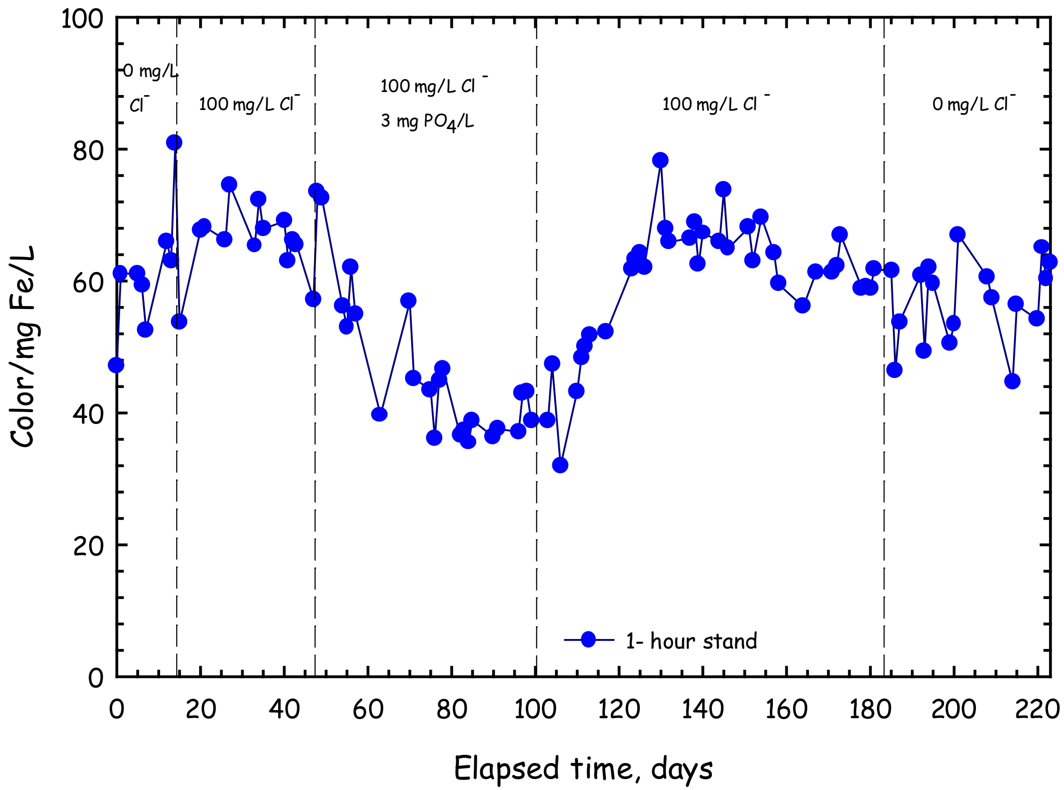
Iron Pipe Studies

Iron Release and Particle Properties

The Effect of Chloride & Phosphate on Iron Release



The Effect of Chloride & Phosphate on Color



Particle Generation Reactor

DO electrode

Gas feed line

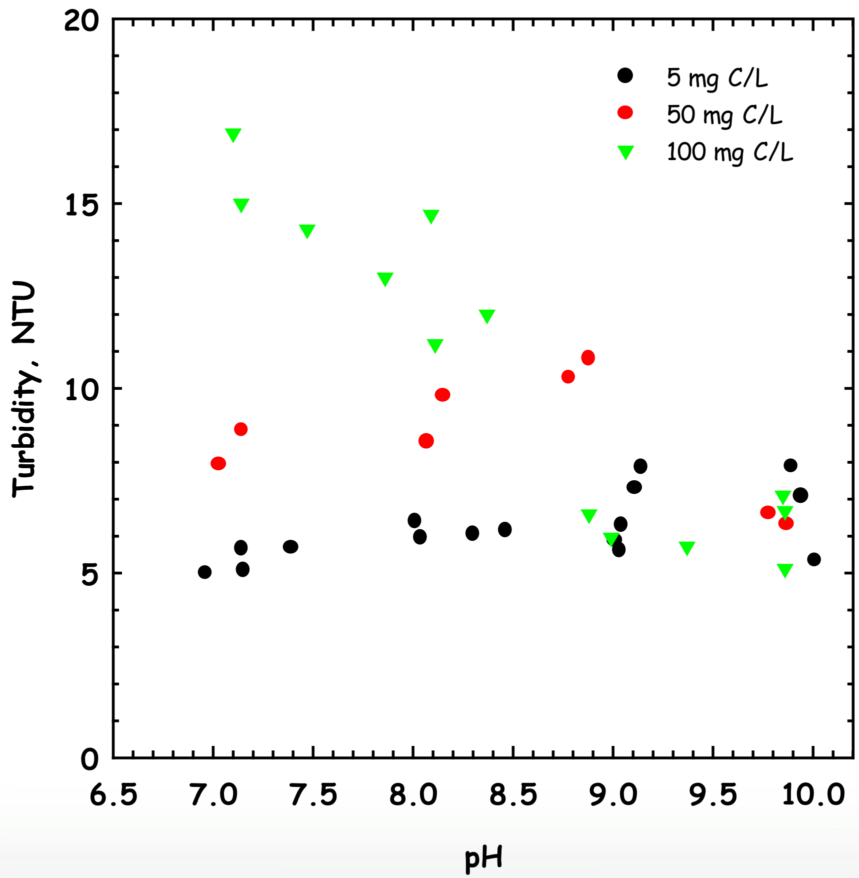
1.2 L cell

pH electrode

Acid/base titrators

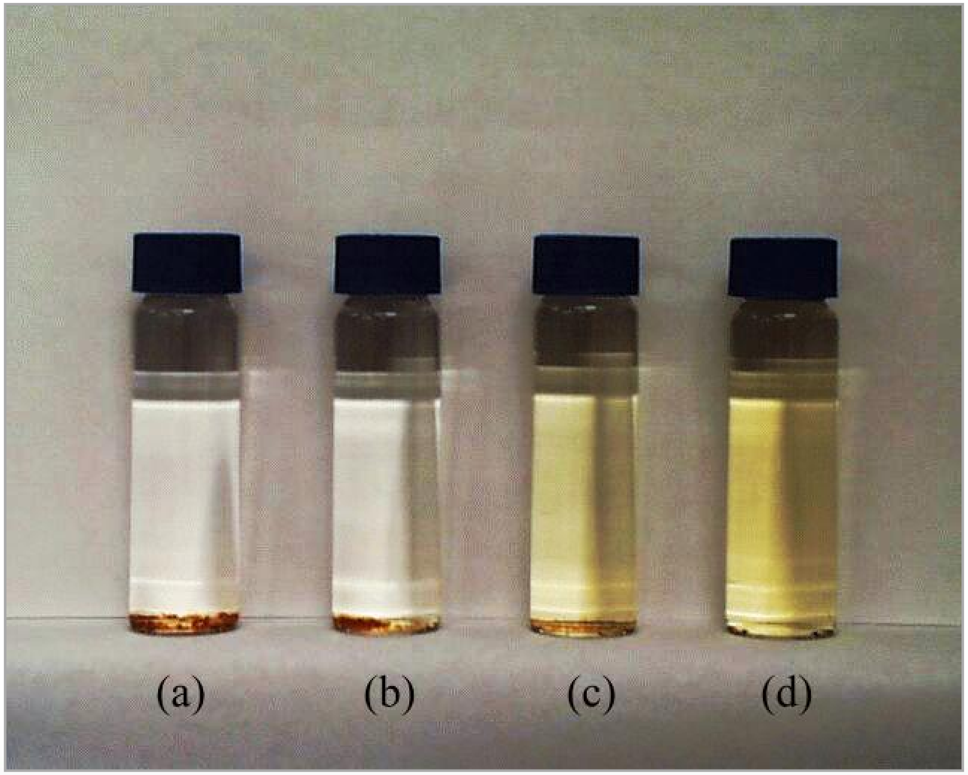
The Effect of DIC & pH on Turbidity of Iron Suspensions

Fe_{tot}= 5 mg/L, DIC= 5 mg C/L, 0.122 atm O_2, 23°C



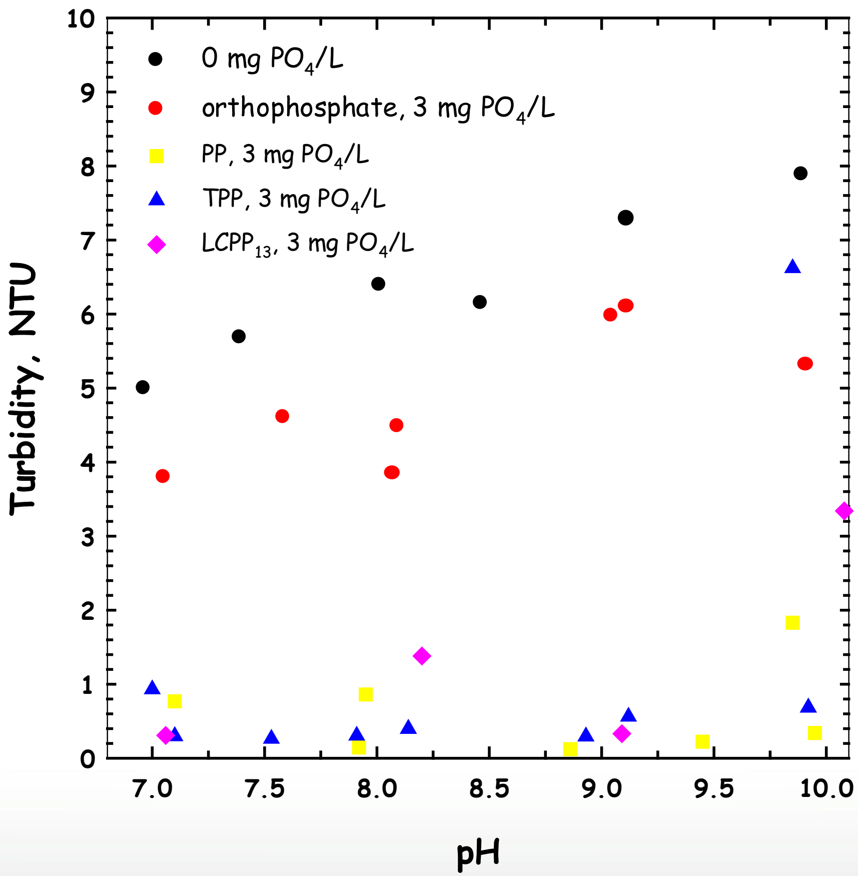
The Effect of pH on the Stability of Iron Suspensions

5 mg Fe/L, DIC= 5 mg C/L, 22°C, PO_2=0.122 atm
pH= (a) 7, (b) 8, (c) 9, and (d) 10



The Effect of Phosphate-Based "Corrosion Inhibitors" on Turbidity

Fe_{tot}= 5 mg/L, DIC= 5 mg C/L, 0.122 atm O2, 23°C

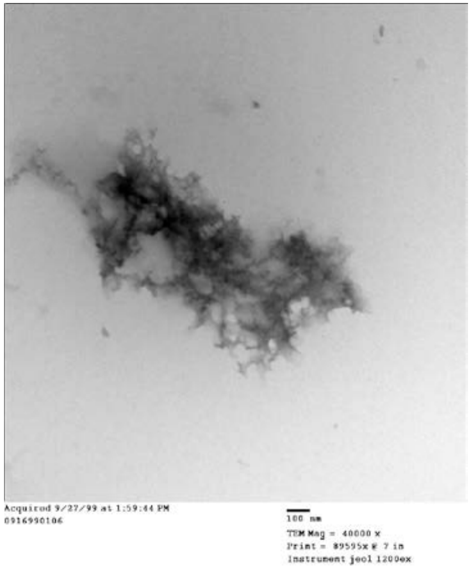


The Effect of Orthophosphate on Iron Suspension Stability

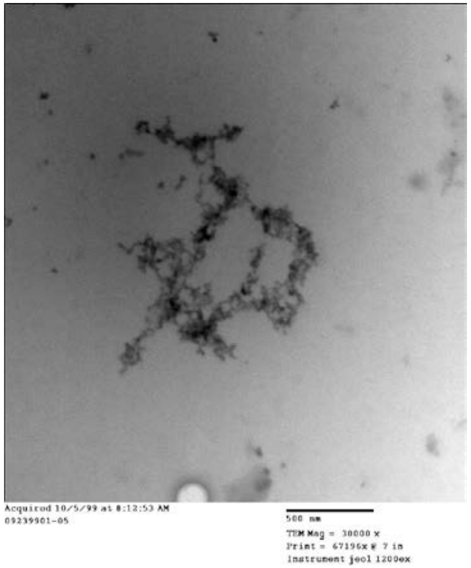
5 mg Fe/l, PO_2= 0.122 atm, pH=8, DIC= 5 mg C/L, 22°C

The Effect of Orthophosphate on Iron Colloids

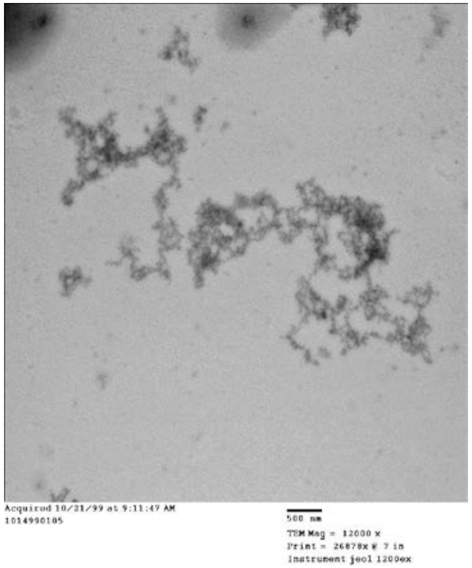
TEM micrograph of iron particles
1 mg Fe/L, pH=7.85 to 7.89, 22.5 to 23°C, DIC= 5 mg C/L, PO_2=0.122 atm



0 mg PO_4/L
(crystal)

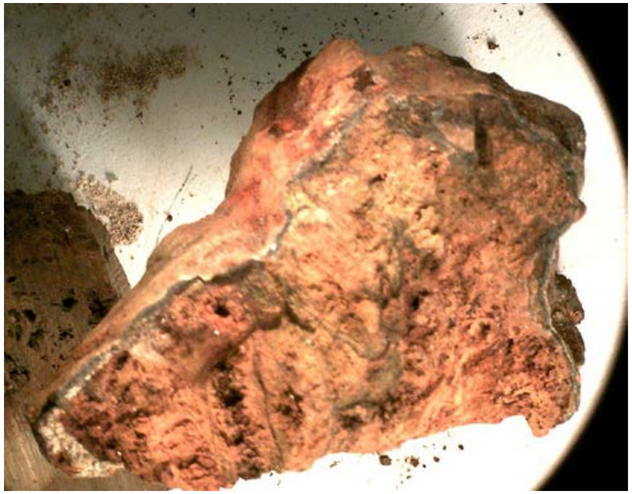


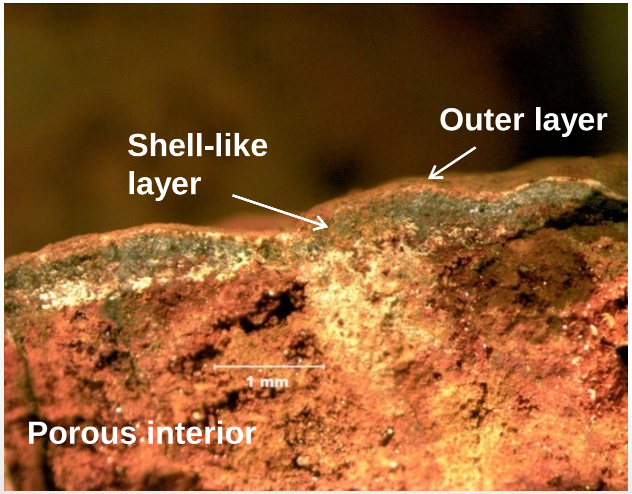
0.5 mg PO_4/L

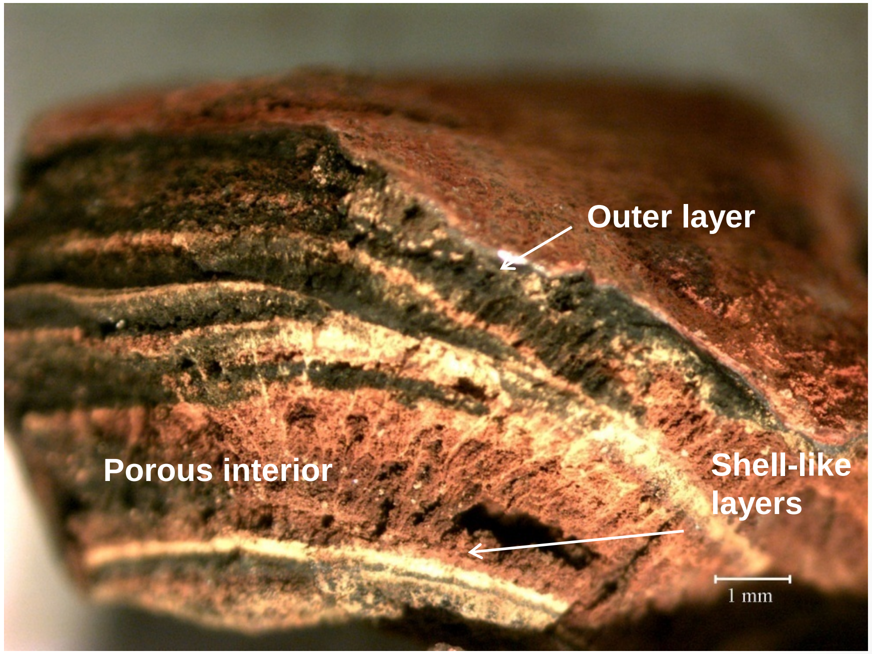


3 mg PO_4/L (am)

Iron Corrosion Scale







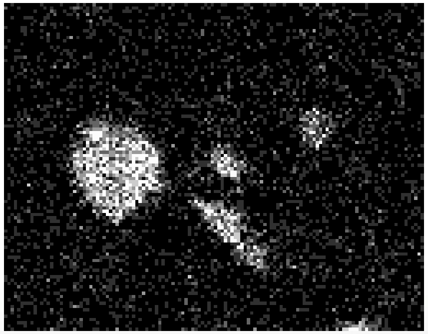
The Role of Microorganisms?

Sulfate Reducing Bacteria (SRB)

Iron drinking water main

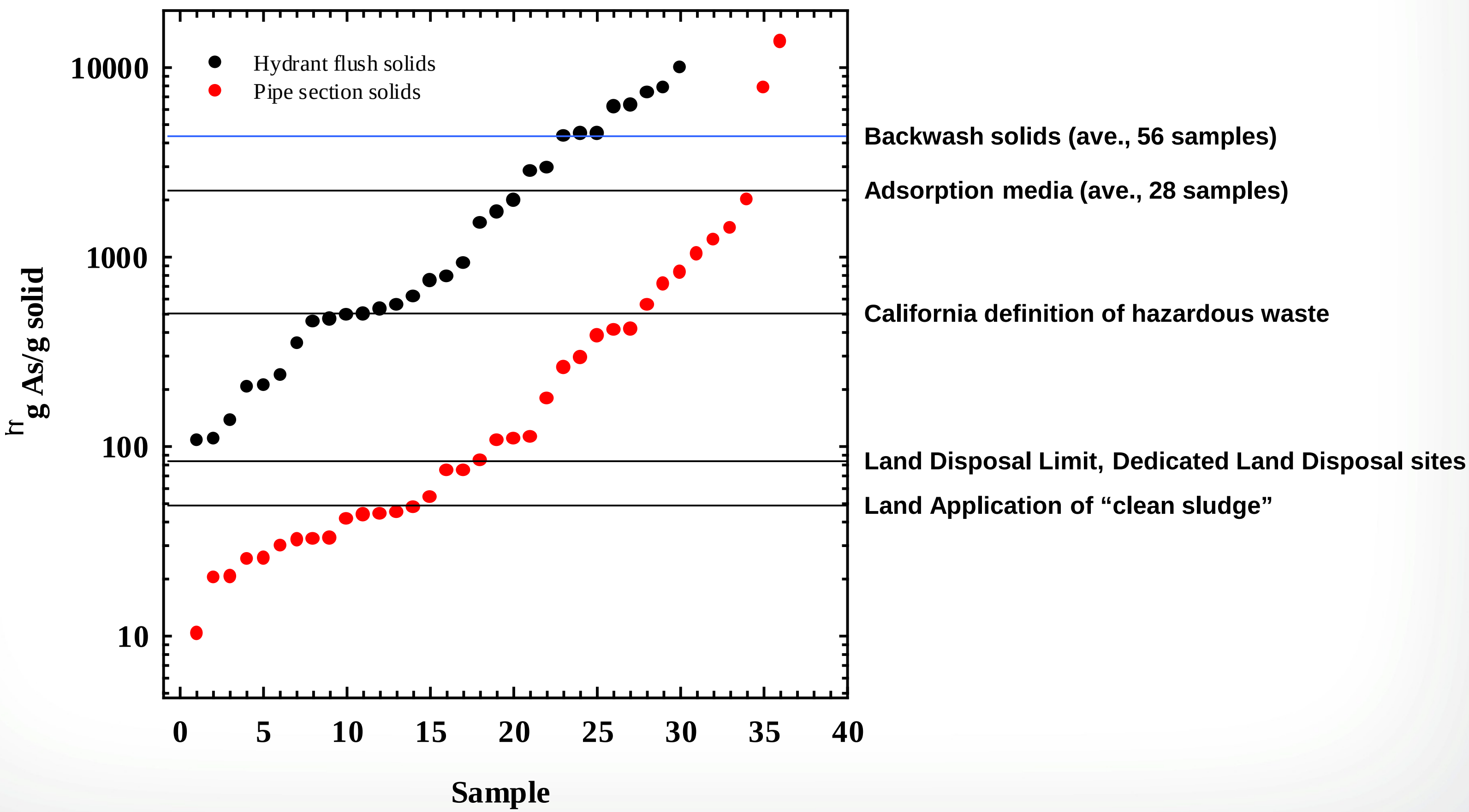
Scale structure

SEM micrographs and Elemental mapping



Corrosion Studies

Arsenic Accumulation in Distribution System Solids



Conclusion

- Iron release is complicated, impacted by many factors, and therefore requires a multi-disciplinary study approach
- Water quality can impact iron release and appearance of iron suspensions
- Specific ions, such as chloride and sulfate, can aggravate iron release, while others like carbonate and orthophosphate can reduce release
- The structure and chemistry of iron corrosion scales can be useful in developing release models
- The role of biofilms is important, but not well understood

Questions?